NEW PLAYBOOKS OF SCIENCE

By HERBERT McKAY

TOYS AND INVENTIONS

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HERE are some of the questions answered in this chapter. See if you can answer any of them before reading the chapter. Try again when you have read the chapter.

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"GEORGE" is the familiar friendly name of the automatic pilot which marvellously controls the flight of aeroplanes. On a long flight, extending over hundreds or thousands of miles, and lasting for many hours, it would be a tedious job for the pilot if he had to work the controls all the time. When this was necessary it was indeed a terrible strain watching hour after hour for any tendency of the plane to dive down, or climb up, or to tip up at one side or other. And the pilot had to be ready to correct such tendencies before any harm was done. Such a strain on the pilot is no longer necessary. On a long straight flight he can "hand over to George", and reserve his energy for the time when exciting things begin to happen: the kind of things that need a human intelligence to direct them.

"*George's Grandfather*"

Like many other inventions, the automatic pilot arose out of a toy. George's grandfather was a spinning top!

There are few people who have not at some time or other spun a top, and there must be thousands of people who have wondered at the odd behaviour of a top. It seems such a dead thing when it is not spinning. We can move it about just as we like, and it does not attempt to resist the movement. As for making it stand upright on its peg, well, that is next door to impossible. But give the top a good spin by beating it with a whip, or by winding cord round it and drawing the cord away suddenly—it is almost as if the top came alive. If we had not seen it so often we should be amazed to find the top stand upright on its peg, like a living thing. If we strike the spinning top we feel it resist the blow, and we see it move in an unexpected way: the upper end of the peg moves slowly in a circle. A skilful top-spinner can take up the spinning top on his hand, throw it in the air, and catch it on his hand with the peg still upright. Professor John Perry was one of many people who studied the behaviour of tops. He fascinated an earlier generation by his lecture and book on *Spinning Tops*. And before him the great Lord Kelvin devoted time and thought to the study of spinning things.

Why a Top Falls Over

There are many questions we can ask ourselves about spinning tops; the better the answers we can get to these questions, the better we shall understand how spinning tops work. The first question is: Why does a top fall over when it is not spinning? The answer is not difficult to find. The top, like any other object, has a centre of gravity (or centre of weight); that is the point where the weight of the top pulls it down. If we could have an exact balance, with the centre of gravity of the top exactly over the end of the peg, then the top would stand upright. But the least disturbance—a touch of the finger, a shake of the ground, or a breath of air—would move the centre of gravity out from the peg, and the top would begin to fall over.

Duodeconal Balancing

Quite a number of balancing tricks depend on keeping the centre of gravity inside the base of the object. On a smooth table we put one of the new duodeconal threepenny bits, upright on one of its edges (Fig. 1). That is easy enough. The centre of gravity is half-way up the coin, and the coin would have to be tilted over quite a little way before it was outside the base. Now we place a second coin on top of the first. It is not quite so easy to balance it. The centre of gravity of the upper coin is three times as high up as that of the lower coin. A slight movement of the lower coin would carry it outside the base and so upset the balance. Still, it is not hard to balance one coin on another. Most people can manage three or even four coins, one over another; but each additional coin increases the difficulty of getting an exact balance. If you can balance six, one over another, you have achieved something.

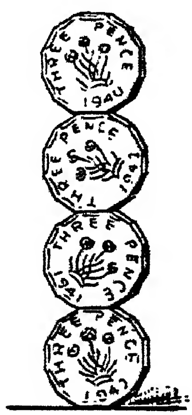


Fig. 1.

A Stick on a Finger

Another easy trick is to balance a stick on an extended finger. This trick is a sort of opposite to the previous one. In balancing coins one on another we try to arrange them with the centre of gravity of each coin over the small base on which the lowest coin stands. The secret of balancing a stick on the finger is to move the base, when necessary, so that it is always under the centre of gravity of the stick. The top of the stick begins to fall over to the right; we move the finger to the right, and so keep the base under the centre of gravity, which is in the middle of the stick. We may move the base so far that the stick begins to fall over to the left; we counter this by moving the finger to the left, and so, by small movements, we manage to keep the base under the centre of gravity. We have to keep our eyes on the top of the stick so as to detect instantly any tendency to fall; then we can counter the tendency before the movement has gone too far.

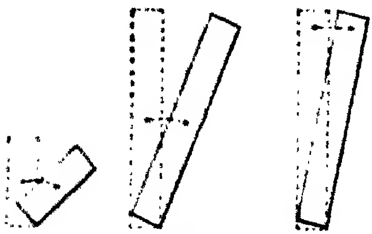


Fig. 2.

The longer the stick, in reason, the easier it is to balance it on the finger (Fig. 2). If the stick is short, a very slight movement of the centre of gravity gives it a considerable tilt. With a long stick the movement of the centre of gravity must be much greater to give the same tilt. If the stick is top-heavy so much the better. The centre of gravity is high up, and a small movement gives the stick a very slight tilt.

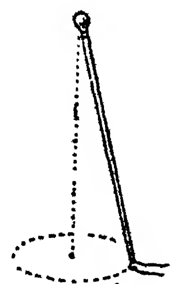


Fig. 3.

One of the most interesting things to do with a balanced stick is to counter the tendency to fall over by moving the finger on which the stick is balanced round and round in a circle (Fig. 3). It is not a very easy trick to perform, but after a little practice it becomes quite manageable. A

rather light stick, about 6 feet long, is easier to manipulate than a shorter one. The difficulty to be overcome is to move the end of the stick just quickly enough to counter the tendency to fall over. When that is done the stick may be given a considerable tilt inwards towards the centre of the circle, and still it does not fall over. By moving the finger rapidly we give the stick a tendency to fall in all directions at once, or almost at once, and so we neutralise the tendency to fall in one direction only. Thus, by spinning the end of the stick in a circle we can balance it with its centre of gravity outside its base. The greater the slope we allow on the stick the more rapidly we have to spin the end in order to preserve the balance.

Why a Top Doesn't Fall Over

Now let us come back to the top. We want to know why a top does not fall over when it is spinning. We have to turn the above process upside down, as it were. In the balanced stick we kept the upper end more or less in the same position by spinning the lower end in a circle. The stick was spun so as to trace out the surface of a cone, or top shape. And of course every point on the stick is spun in a circle. The top is like the cone upside down, and there appears to be the same kind of effect. It is as if the spinning of the top spread any tendency to fall all round the circle, and so neutralised it.

What the Axis Is

The line about which an object spins is called its axis, or axis of rotation (Fig. 4). When we watch objects spinning

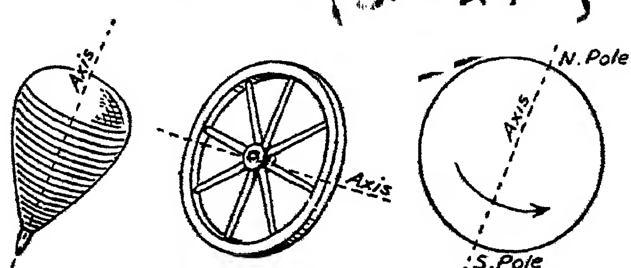


Fig. 4.

we want to be able to say at once where the axis of rotation is. The axis of a spinning top is the line down the middle of the peg; when the top is spinning, the axis is usually almost upright. The axis of the earth, the line about which it spins, is the line joining the North and South Poles. The axis of a turning wheel is the line along the middle of the axle. The axis of the stick which was held on the finger and whirled round, is the line from the upper end of the stick to the middle of the circle in which the base is whirled. An object may of course be whirled round in many different ways; there is a different axis for each way. Fig. 5 shows two axes for the same spinning object.

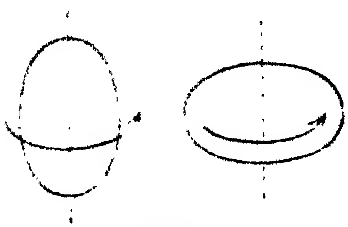


Fig. 5.

When an object is spinning, the spin keeps the axis pointing always in the same direction. We are not thinking of slowly spinning things like cart-wheels; friction with the road is far more important in such cases than the very slow spin; the small effect of the spin is swamped by the much larger effect of friction. No, we have to think of rapidly spinning objects, where friction is not great enough to interfere too much with the motion. Rapidly rotating flywheels are examples of the spinning motion that is not usually swamped by friction.

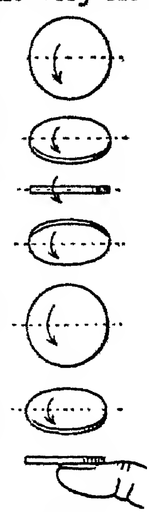


Fig. 6.

The Arts of Tossing and Trundling

It is easy enough to illustrate the effect of spinning on the axis of rotation. If we throw a penny into the air it appears to move at random. But if we send it spinning into the air, with a flick of the thumb, we can see that the axis (across the middle of the penny) remains horizontal, and we can tell pretty well how the penny will come down (Fig. 6). As for predicting whether heads or tails will come up, that is another matter alto-

gether; it depends on exactly how many complete spins the coin makes, and he would be a super-clever performer who could give the exact force to the flick to ensure the exact number of spins required to make his prediction come true.

Every child who has trundled a hoop knows that the faster the hoop turns the easier it is to keep it upright. The axis of the hoop is the line across the middle and at right angles to the hoop. If we start off with the hoop upright the axis is horizontal, and it remains horizontal so long as we keep the hoop trundling rapidly. The faster the hoop moves the more stable is its motion.

There is another way in which we can amuse ourselves with a hoop, and at the same time learn something about the way in which it moves. We can throw the hoop, and see it move through the air at random. Then we can throw it and give it a spin, just as it leaves the hand, by means of a sharp downward jerk. After a little practice we find that we can spin the hoop and throw it so that it remains upright till it reaches the ground again and runs back to us.

Aiming a Disk

A sheet of cardboard can give an even more effective example of the effect of a spin (Fig. 7). We want a sheet

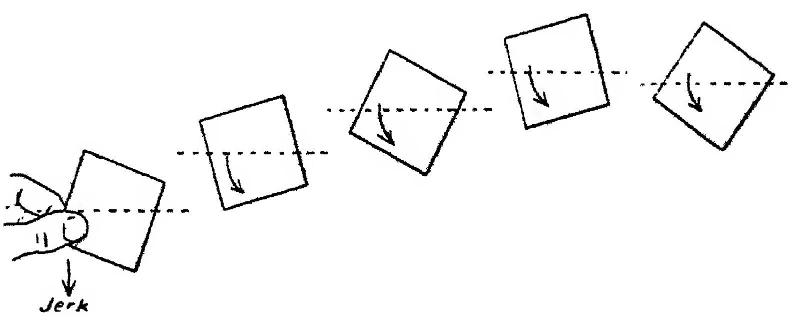


Fig. 7.

about a foot square, but the exact shape does not matter. We try to throw the card at a mark twenty feet or so away. It turns out to be all but impossible. Try as often as we like,

throw the card edge on so that it may readily cut through the air, it is all in vain. The air catches the card, turns it broadside on, and keeps it from getting anywhere near the mark. Now let us throw the card again, but this time give it a spin as it leaves the hand; a sharp downward jerk will do that. With a little practice we find that we can hit the mark, or at any rate get somewhere near it. The axis of rotation of the card is a line across the middle at right angles to the card. The axis keeps a constant direction, and so the card keeps edge on, and sails through the air towards the target. A small card may be sent spinning through the air by a flick of the finger. The faster the card is made to spin the more accurately does it fly towards the mark. The axis of rotation in this case is a vertical line through the middle of the card.

The Juggler's Art

Jugglers are well aware of the effects of rotation. Many of their most spectacular tricks depend on giving rapid spins to the objects they are juggling with; a juggler needs strong wrists, and considerable dexterity in making things spin. Plates thrown at random appear to move at random; a juggler throwing them like this with one hand could not be sure how they would reach the other hand. But if he gives each plate a spin as it leaves his left hand, he knows that it will reach his right hand in the same position as it left his left hand. If it was thrown vertical, it will remain vertical (Fig. 8).

Fig. 8.

If you wish to emulate the feats of jugglers it is best to start with objects that do not easily break. Until you have acquired some facility in spinning, accidents will be frequent. Circles of thick cardboard or thin wood can be used for vertical spins, cork table mats are even better. In any case hold the disk upright, and give the edge a sharp downward jerk as you throw it upward and over toward

the other hand. An old hat may be used for practising a horizontal spin; if you can get a really good spin on it you may be able to put your head under it and catch it neatly.

What the Boomerang Does

The little toy boomerang depends for its effectiveness on the spin we give to it (Fig. 9). We cut out the boomerang shape in thin card or thick paper. We place it near the edge of a book, sloping upwards, and with one of its arms projecting over the edge. With a flick of the finger we can send it speeding through the air with a spinning movement. With any sort of luck the little boomerang reverses, and comes back along the way it went. The axis of rotation is the perpendicular line through the middle of the boomerang. The axis keeps the same slant during the movement, and so the boomerang is in position at the end of its flight to slide back again more or less along the same path.

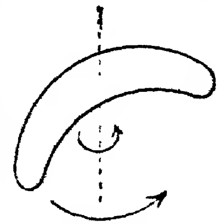


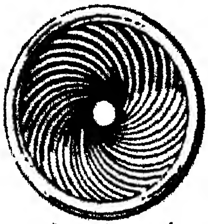
Fig. 9.

Guns and Tops

Guns and spinning tops! They seem to be poles apart; but there is an important connection between them. Improvements in gunnery arose out of a study of spinning tops. In the old days, up to about 1730, nearly all guns had smooth bores, and all shot were ball-shaped or spherical. The spherical shape was chosen because it would not matter whether such a shot turned over and over. The elongated shot that are used now would not do at all. An elongated shell or bullet would turn broadside on to the direction of flight—the pressure of the air would swing it round; there would be no chance of hitting the target with the point. There was another cause of inaccuracy in the old guns. There had to be a small space—"windage" it was called—between the shot and the barrel of the gun. As the shot sped along the barrel, impelled by the force of the exploding powder, it rocketed from side to side. Its course through the air depended on how it

happened to be moving at the moment when it left the muzzle of the gun. At the last rebound from the side of the barrel it might happen to be moving up or down, or to left or right. The man who was firing the gun could never be sure how the shot would leave it; a grain or two more of powder might have slipped into the charge; there might be small variations in the arrangement of the grains, or in the quality of the powder. The gunner could never be sure, and so his shooting was inaccurate.

Then someone who had watched a top spinning, and who had wondered why the axis of a spinning top should remain upright, thought of applying the idea to guns. He thought of a way of making the shot spin. The only place where the shot could be made to spin was in the barrel, and accordingly spiral grooves were made inside the barrel (Fig. 10). Instead of allowing space for windage round the shot, the inventors arranged to have the shot forced into the grooves; in early guns this was sometimes done by ramming the shot home with a mallet. When the charge was fired, a mass of hot compressed gas was suddenly formed; it pressed on the shot and drove it along the barrel. The shot was thus compelled to follow the direction of the grooves. That is, it was made to spin.



Looking through gun barrel, showing rifling

Fig. 10.

Benjamin Robins, who died in 1742, is often credited with the invention of guns with spiral grooves, but such guns were in existence long before his time. He was the first, however, to tackle the matter scientifically, and to give a real impetus to the manufacture of such guns. After Robins's time a ring of softer metal was added to the hard steel of the shot, so that a ramrod could force this metal into the grooves. It was an obvious improvement to let the explosion gases press the metal ring into the grooves, as they do in modern guns.

What "Rifles" Are

Spiral grooves, like those made in the barrels of guns, used to be called "rifles". A gun with such grooves was called a rifled gun. The name was used for cannon as well as for small guns meant to be held to the shoulder. Now the word "rifle" is used only for such small rifled guns.

The grooves, or rifling, may go once round the barrel, so that a shot is given a single turn as it traverses the length of the barrel. That may not seem much of a spin, until we begin to think of the speed at which the shot is travelling: the shot does that single turn in a very short time. Think of a cannon with a barrel 10 feet long. A shot may make a single turn in traversing the 10-feet barrel, and it may leave the gun with a muzzle velocity of 1500 feet per second. Allowing one turn for every 10 feet, the shot would make 150 turns in 1500 feet, so that the spin would be equal to 150 revolutions per second, or 9000 revolutions per minute. And that is a pretty considerable rate of spin.

Elongated Shot

Rifling has made it possible to use the elongated bullets and shells that are now almost universally employed, with the certainty that the shot will continue to move with its axis parallel to its direction at the moment it left the gun (Fig. 12). Any tendency to change is rapidly spread all

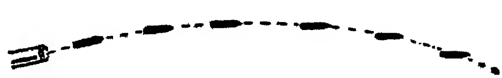


Fig. 11.

round the circle of spin, and so it is neutralised. The inaccuracy caused by windage has also been removed by having the base of the shot pressed into the rifling.

The rifling is made with the curves winding round from left to right (clockwise) looking along the barrel as the gunner looks. The clockwise spin gives the shot a small

deflection to the right (Fig. 12). The gunner knows the amount of this deflection, and so he can make allowance for it when he is taking aim.

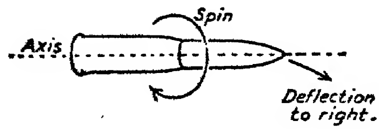


Fig. 12.

So it comes about that the accuracy of modern firearms is largely due to inventions that arose out of observation of spinning tops.

The Gyroscope Arrives

Soon after 1800, though no one seems to be sure of the exact date, a new kind of spinning top was invented. This was the kind of top we call a gyroscope, and sometimes "gyro" for short. In its simplest form the gyroscope consists of a heavy flywheel mounted in a ring (Fig. 13). The wheel has an axle with pointed ends, and

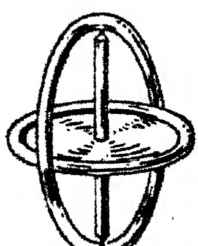


Fig. 13.

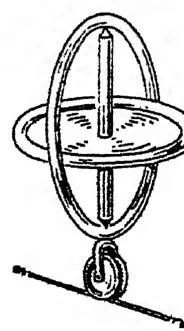


Fig. 14.

these fit into dents in the outer ring. The flywheel may be made to spin by winding cord round the axle, and then drawing it out rapidly. In a well-made gyroscope, with little friction at the pivots, the wheel goes on spinning for a considerable time, and the gyroscope is then a well-behaved top. The axis is of course the line down the

middle of the axle. If we set the flywheel spinning with the axis vertical, it will remain vertical. We can hold the spinning gyroscope securely balanced on an extended finger, or on a piece of stretched string. We can throw the gyroscope in the air and, with a little skill and some practice, we can catch it again on the finger. Sometimes toy gyroscopes are mounted on small wheels; they may be made to run along cords without falling off (Fig. 14).

At first the gyroscope was nothing more than a toy, a very interesting scientific toy, but still only a toy. Later on it developed into a most important invention, or rather a series of inventions.

The gyroscope and the spinning top have been used to explain or illustrate many interesting natural phenomena. Unless it is very heavy we can readily pick up a revolving gyroscope and move it bodily from place to place. But if we try to change the direction of the axis we find a vigorous resistance to the change. It almost seems as though the gyroscope were alive and resented such attempts to change its axis. Until we have got used to it we may well be surprised to find so vigorous a resistance, and to find also that the gyroscope actually moves in an unexpected direction, quite different from the direction in which we tried to push it.

The Earth a Gyroscope

The earth itself is a gigantic gyroscope. It revolves on its axis once in about 24 hours. That is pretty quick for so large a body as the earth. A person or thing at the equator is spinning round at the rate of 25,000 miles in 24 hours, or more than 1000 miles an hour (Fig. 15). The rate of movement dies away to zero at the poles. An important result of the spin is that the direction of the earth's axis does not change. The attractions of the sun and moon would cause changes in the direction of the axis if it were not that such changes are resisted by the spinning motion.

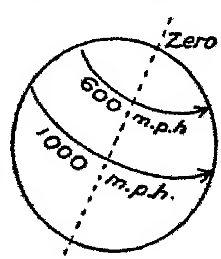


Fig. 15.

We know that the earth goes round the sun in an orbit which is elliptical in shape. This ellipse is nearly a circle; in fact, if it were drawn to scale it would take a sharp eye to detect that it was not a circle. The flat surface on which the orbit is drawn, a page of this book, is called the plane of the orbit. We can imagine the plane of the real orbit filling all the space within the orbit, and spreading out all round it.

Imitating the Earth's Movement

Suppose we have a large drawing of the earth's orbit. We might place a gyroscope on the orbit and set it spinning with the axis vertical. We could take up the gyroscope and move it round the orbit, and so imitate a planet going round the sun. There is no difficulty till we try to tilt the axis away from the vertical; as soon as we try to do that we find that the gyroscope sets up a vigorous resistance.

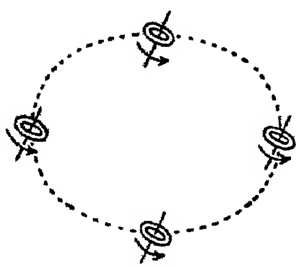


Fig. 16.

Now let us tilt the axis of the gyroscope so that it makes an angle of 23° or 24° with the vertical, and then set it spinning. Again we can move the gyroscope along the orbit (Fig. 16); and again there is no difficulty till we try to change the tilt of the axis; then there is the usual resistance. We notice that the axis keeps a parallel course all round the orbit. At one point on the orbit the upper end of the axis is tilted in towards the centre; at the opposite point on the orbit the upper end of the axis is tilted out from the centre. Half-way between these extreme points the axis is across the orbit and neither end is tilted inward.

We have been imitating the motion of the earth round the sun. The actual tilt of the earth's axis is about $23\frac{1}{2}°$ away from the perpendicular to the plane of the orbit; equally we might say that the equator is tilted at $23\frac{1}{2}°$ to the plane of the orbit. That is a very important tilt for everyone and everything living on the earth. It is the

tilt of 23½° that gives us the changing seasons, with all the variety and interest they add to life.

Why we have Seasons

Just as the axis of the gyroscope was tilted over, so at one part of the year the northern end of the earth's axis is tilted over towards the sun (Fig. 17). Of course the

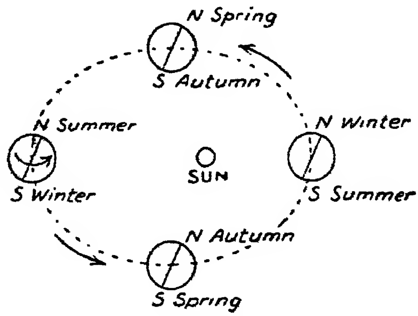


Fig. 17.

northern half of the earth then gets more light and heat than the southern half which is tilted away from the sun. That is the period of northern summer and southern winter.

Six months later the earth is at the opposite end of its orbit, and conditions are reversed. The South Pole (the southern end of the axis) is tilted towards the sun, and the North Pole is tilted away. That is the period of southern summer and northern winter. June and July are the middle of northern summer and southern winter; December and January are the middle of northern winter and southern summer. Half-way between summer and winter, in March and September, we have the equable weather of spring and autumn, when neither pole of the earth is tilted towards the sun.

Foucault's Gyroscopes

Foucault, a great French scientist of the middle of the nineteenth century (1819-1868), is sometimes credited with

the invention of the gyroscope, though it was certainly known before his time. What Foucault did was to add to the value of the gyroscope by using it in interesting and ingenious ways. The gyroscopes he used were made with extreme care. He wanted most of all to reduce the friction at the pivots on which his gyroscopes rotated; he wanted as little friction as possible. He also wanted his gyroscopes to be able to rotate with the axis pointing in any direction.

In the drawing of a well-made gyroscope (Fig. 18) you will see that the flywheel is mounted on gimbals, or metal rings that can be rotated. The outside ring is fixed; it is merely a frame for holding the gyroscope. The ring A is upright, and it can be turned about the vertical axis CD; this ring is pivoted to the outside casing. Now look at the ring B; it is pivoted to the ring A, and it can be rotated about the horizontal axis EF. The flywheel is pivoted to the ring B. That is the kind of gyroscope that was used by Foucault. The special point about it is that the flywheel can be tilted in any direction. We can tilt the ring B, up or down, just as much as we like. Then we can turn the ring A to left or right, again just as much as we like. Between the two movements we can get any direction we like for the axis GH of the flywheel. All the pivots were smooth in Foucault's gyroscopes and very carefully mounted, so that the friction should be as little as possible.

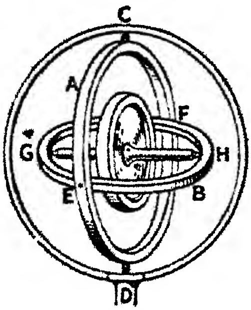


Fig. 18.

There are other ways of mounting a gyroscope (Fig. 19). Half the ring A may be removed, and the lower half which remains may be mounted so as to turn in a socket. This mounting gives the same freedom of movement as that previously described. In another kind of mounting the flywheel

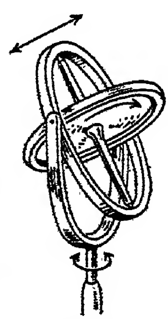


Fig. 19.

is at the end of a bar, and it is balanced by a weight at the other end of the bar (Fig. 20). The middle of the bar is pivoted so that it can turn up or down or from

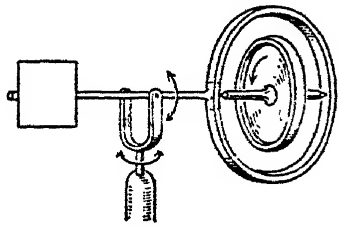


Fig. 20.

side to side. Gyroscopes also are sometimes mounted on a single gimbal which may permit movement round a vertical axis only, or round a horizontal axis only.

How the World Goes Round

Let us come back to Foucault. Foucault thought that if he set a gyroscope spinning rapidly its axis would keep a constant direction. The spin of the earth would carry every object in the room, and the room itself, in a rotation round the fixed axis of the gyroscope; this rotation is from right to left, facing outwards. So, if the axis of the gyroscope were horizontal, the room would move round it from right to left. Or, what is the same thing, the horizontal axis would appear to move round from left to right. If there were a lot of friction at the points where the gyroscope is pivoted, this would check the rotation; the pivots rotate with the room, only the flywheel is fixed in direction. But Foucault made arrangements to reduce the friction almost to nothing by having his gyroscopes mounted on knife-edges. The experiment was completely successful. What Foucault had predicted actually happened: the gyroscope appeared to rotate steadily from left to right. And thus he showed, inside the walls of a room, that the earth rotates from right to left. He was able also to find the time of rotation by noting how long the gyroscope took to make a complete movement from left to right and back again to the original direction.

The Gyroscope as a Clock

Foucault went even further than that. He saw that the spin of the earth would affect his spinning gyroscope by constantly giving it a spin in its own direction. The spin of the big gyroscope, the earth, would control the spin of the little gyroscope, even though it was rotating much more slowly. We have seen that there was very little friction in Foucault's gyroscopes, and they went on spinning for a long time. Slowly the axis of one of these gyroscopes moved until finally it took up a position parallel to the axis of the earth, so that it was spinning in the same direction as the earth; if it were set spinning in the opposite direction it would turn over, so that the two spins were alike. With his gyroscope spinning in that position Foucault could make very exact observations, because the spin of the earth would no longer interfere with the spin of the gyroscope. He might have used the gyroscope as a clock, by fixing a pointer to the axis and placing a dial under it; the gyroscopic clock would certainly not show Greenwich mean time, but sidereal time, which is based on the exact time of rotation of the earth.

The Gyroscope Measures Latitude

Here is another extraordinary thing about this extraordinary gyroscope. In diagram A (Fig. 21) you will see that P is a point on the earth's surface in latitude l; l is the angular distance of P from the equator. NS is the axis of the earth, which rotates in the direction shown by the arrow. Diagram B shows a gyroscope at P; it is one of Foucault's gyroscopes which has been set with its axis parallel to the axis of the earth; the gyroscope has to be drawn out of scale so that we can see it. In diagram C the axis only of the gyroscope has been left in. PH is the direction of the horizon at P; it is actually the tangent at P to the great circle of the earth.

Now let us look at an easy bit of geometry. We know that GP (axis of the gyroscope) is parallel to NS (axis of the earth). PH cuts across the parallel axes, so we know that angle x = angle y. Now look at triangle PHO. It has a

right angle at P, where the tangent meets a radius of the circle; so angle y + angle z = a right angle (the other right angle of the triangle); that is, z is the complement of y. But z is also the complement of l. So $l = y$; and as $y = x$, we have $l = x$. That is, the angle x, between the axis of the gyroscope and the horizon, is equal to the latitude of P. We can measure the angle x, and so we can find the latitude l.

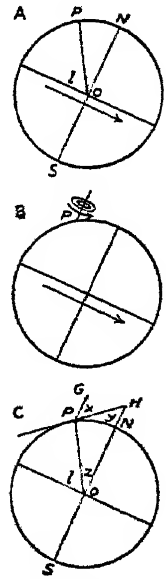


Fig. 21.

Let us put together the remarkable things that Foucault had accomplished with his gyroscopes. Without observing the stars, without even leaving the room in which he worked, he had proved that the earth rotates, he had measured the time it takes to rotate, and he had found the direction in which it rotates. The direction of the axis of his gyroscope gave him the north and south line; a line across the axis at right angles gave him the east and west line. Most astonishing of all, he had succeeded in measuring his latitude. Not a bad series of results to obtain by observation of what is little more than a spinning top. We have called the gyroscope "extraordinary"; but those used by Foucault were really ordinary gyroscopes observed by a man with a very remarkable brain.

The Effect of a Double Gyroscope

We have seen that a spinning gyroscope can be carried bodily from place to place; there is no difficulty until we try to change the direction of the axis. We might have a platform attached to the axis of the gyroscope. We could tilt the platform round the axis in the same direction that the flywheel is spinning, or in the opposite direction; there would be no resistance because we are not attempting to change the direction of the axis. But an attempt to tilt the platform in any other direction would be met with the

usual resistance of the gyroscope to change of the direction of its axis.

Now suppose we have two gyroscopes attached to the platform. We fix them with their axes horizontal, and at right angles to each other (Fig. 22). The gyroscope A would only permit rotation of the platform about its own axis. But any tilt of this kind would tilt the axis of gyroscope B, and so it would be resisted. Any attempt to tilt the platform about the axis of B would be resisted by A. Between them the two gyroscopes prevent tilting in any direction. The double gyroscope could still be carried about from place to place, but it would resist any attempt to tilt it in any direction out of the horizontal.

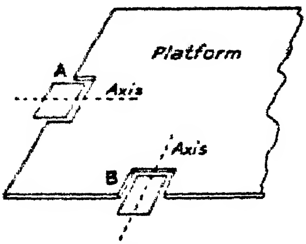


Fig. 22.

What Piazzi Smyth Did

One can readily see how convenient it would be to have a steady platform on which to stand when making observations. On land it is easy enough to have a steady platform; at sea it is far from easy. A ship may be rolling or pitching in a stormy sea: rolling from side to side, or pitching from stem to stern. An unfortunate navigation officer has to take observations in these conditions with everything swaying about him. How much more simple the observations would be if they could be taken from a stable platform that did not pitch and toss with the ship.

Somewhere about 1856 Professor Piazzi Smyth had the idea of using gyroscopes to stabilise a telescope stand on board ship. He used several heavy gyroscopes, and he had to think out ingenious methods for keeping them in rapid rotation. He solved this and other problems; the apparatus was tested on a ship, and it worked satisfactorily. Since then gyroscopes have been used to steady gun platforms and swinging cabins in ships.

The Directional Gyro

The property of the gyroscope of keeping its axis pointing continually in the same fixed direction suggested its use as a compass. The gyroscopic compass is commonly called a *gyro-compass*. In one form it is called a *directional gyro*, because it is used to give direction.

The directional gyro is used on aeroplanes. Its axis can be set in any direction before it is set spinning, and it keeps this direction with sufficient accuracy to enable it to be used as a compass.

The axis is initially set by comparison with the magnetic compass. It can be set in the direction of an intended flight, so that the pilot sees the indicator straight in front of him. He has only to follow his nose, as it were.

There are occasions when the directional gyro is especially important, as, for instance, when the magnetic compass goes out of action. When a plane is turning, everything in it is swung outward, away from the centre round which it is turning. The carefully poised magnetic needle is thrown out of balance, and gives false readings. But the directional gyro remains faithful to its job: the axis maintains its constant direction, and the pilot can rely on it to tell him through how many degrees he has turned.

"*Wander*"

The directional gyro is not a perfect instrument. Friction at the pivots is reduced to a minimum by the use of ball bearings and knife-edges; but some friction still remains, and this has a slow but continuous effect.

The earth's rotation also affects the directional gyro, and turns it from the direction in which it was set. The error thus introduced is called "wander". The wander may be as much as three or four degrees in a quarter of an hour, and it may be necessary to reset the directional gyro at intervals of fifteen minutes by comparing it with the magnetic compass. Recent improvements in the construction of gyroscopes have reduced the wander, so that they can now be relied upon for much longer periods without resetting.

How the Gyro is Spun

The construction of an efficient directional gyro was far from being an easy matter. To begin with, a way had to be found of keeping the flywheel in rapid rotation. Electric motors can be used, and indeed are used, for this purpose, but on aeroplanes a simpler method is used. Round the rim of the flywheel a number of vanes are fixed, similar to those on undershot water-wheels, but of course much smaller (Fig. 23). A jet of air is directed on to the vanes, and this causes the flywheel to rotate at the necessary speed, which is something like 10,000 revolutions per minute. The jet of air is usually obtained by pumping air out of the casing so as to keep up a partial vacuum of about 4 inches of mercury. This is equal to a pressure of 2 pounds per square inch, and there is a consequent inrush of air, directed across the wheel.

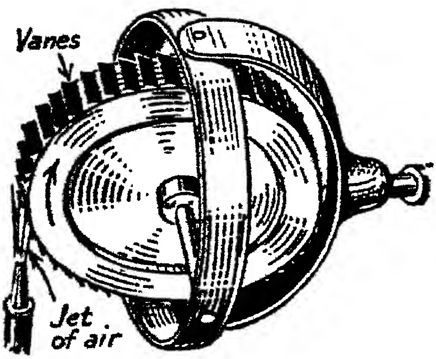


Fig. 23.

There is an ingenious arrangement to keep the flywheel from tilting. Instead of a single jet of air, there are two jets, side by side. If the wheel tilts over to the right, the jet on the left plays on the rim of the wheel and has little effect. The jet on the right plays on the sides of the vanes and drives them back towards the left.

The Venturi Tube

Everyone knows the working of a scent-spray. We have a bottle of scent with an open tube running down into it. We press a rubber ball so as to drive a current of air across the open top of the tube. Scent is sucked up from the tube, and driven out in a spray.

The venturi tube (Fig. 24) is an efficient form of the scent-spray. The tube narrows and then widens out again. There is a side-tube at the narrowest part. A strong current of air through the main tube causes suction from the side tube. In an aeroplane the current of air might be the relative wind—a current of 200 miles per hour, or more.

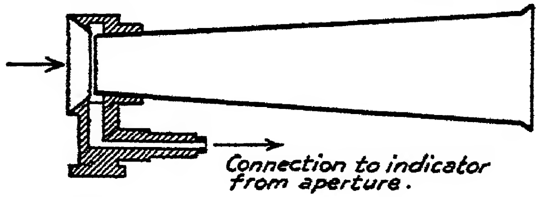


Fig. 24.

A current of this kind can be used to draw air out of the casing of a gyro, and so to produce the necessary partial vacuum.

A double venturi tube has a small tube inside a wider one. It is more powerful in its action than the single venturi tube.

How a Gyroscope Precesses

If we press horizontally on a spinning top near the upper end of its axis, it begins to move, but not in the direction in which we press. The upper end of the axis moves slowly round in a circle; we say that it *precesses.*

Let us think for a moment of the effect of a horizontal pressure at X in Fig. 25A. If the end Y is fixed, say by a hinge, the effect of the pressure at X is to cause rotation about the axis MN. When we are considering spinning things we usually have to look at pressures in this way. That is, we have to think of the axis about which any particular pressure would cause rotation if it were acting alone.

Now look at the diagram of a gyroscope (Fig. 26B). It is spinning about the horizontal axis AB. Suppose we apply a downward pressure at A, one end of the axis; we might for example hang a weight from the end of the axle. If the gyroscope were not spinning, this pressure would cause it to rotate about the horizontal axis CD. But as

the gyroscope is spinning it does not behave in this way; it resists any attempt to turn its axis out of the horizontal. Instead of that—and this is the interesting point—the axis AB of the gyroscope tends to set itself in the direction CD, or parallel to this direction. The axis AB swings round, or precesses, till it is more or less parallel with CD. If the downward pressure is continued for only a short time, the axis moves only a short distance. The pressure would have to be continued for some time before AB finally became parallel to CD.

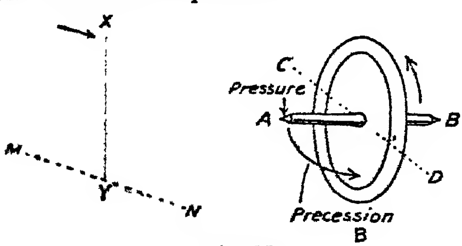


Fig. 25.

The arrow curving round from A toward D shows the direction in which the axis precesses. The precession occurs in such a way that when the final position is reached, the gyroscope is rotating in the same direction as the rotation that would be produced by the pressure which causes the precession.

You will remember that Foucault's gyroscope behaved in just that way. The rotation of the earth exerted a continual small pressure on it, and this pressure tended to make the gyroscope rotate in the same direction as the earth, with its axis parallel to the earth's axis.

Precession of the Earth

The earth is a gyroscope, and it precesses like any other rotating body if there is a tug or a push on the axis. There actually is such a tug.

The axis of the earth rolls slowly round on the surface of a cone, just as the axis of a top moves when it precesses. The movement is very slow; it takes about 26,000 years for a complete turn. The angle turned through in a year is:

$$\frac{360}{26{,}000}\text{ degree} = \frac{360 \times 60 \times 60}{26{,}000}\text{ seconds}$$
$$= \text{about 50 seconds of arc.}$$

This angle is called the *constant of precession.*

The precession is in the opposite direction to the rotation and revolution of the earth, so the length of the year, as measured from spring equinox to spring equinox, is a little less than the time taken by the earth to make a complete revolution in its orbit (Fig. 26).

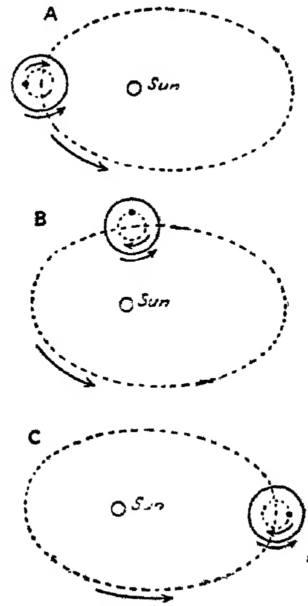


Fig. 26.

"*Changing Seasons*"

Another way of saying the same thing is to say that the spring equinox is moving backward along the orbit. Northern summer now occurs when the earth is farthest from the sun (about 94½ million miles), and northern winter when it is nearest to the sun (about 91½ million miles). In 13,000 years precession will have carried the seasons halfway round the orbit. Northern summer will then occur when the earth is nearest the sun, and northern winter when it is farthest away. Northern summers will then be hotter and northern winters colder than they are now.

So there is something after all in what people say about the seasons changing. The change is so slow, as we have seen, that it could only be observed across periods of thousands of years. Those who profess to notice the change in the course of a single lifetime must be exceptionally acute observers, with microscopic eyes, and the imaginations of astrologers.

The Gyro-compass

A gyroscope swung on gimbals can have its axis set in any direction. Suppose we clamp the inner gimbal ring, so as to prevent any tilting up or down, then the gyroscope can only swing so that its axis moves to and fro horizontally.

In this form the directional gyro is known as a gyroscopic compass or gyro-compass (Fig. 27).

Instead of setting with its axis parallel to the earth's axis, as Foucault's gyroscope set, the gyro-compass sets with its axis north and south. That is, it sets as nearly parallel to the earth's axis as it is allowed to. There are better means

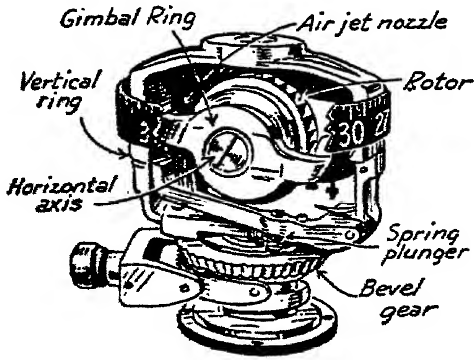


Fig. 27.

now of cutting down friction at the pivots than Foucault ever had. Ball bearings have been introduced since his time; they were developed in connection with bicycles. Much more is known about the use of lubricating oil. A carefully made gyro-compass, with modern improvements, rapidly sets to the north and south direction. The axis points to the true, or geographical north, so that there is no trouble about magnetic deviation.

Ships and Submarines

The magnetic compass is not a very satisfactory instrument in a ship built largely of iron and steel. The large masses of iron and steel draw the compass needle away from the north. In addition to this, the hammering to which a ship is subjected whilst it is being built gives the ship a permanent magnetism which also distracts the compass. A great many corrections have to be made for the permanent and temporary magnetism of the ship. Allowances must also be made for the fact that the compass

needle points to the Magnetic Pole and not towards the geographical North Pole. The amount of deviation from the true north varies from place to place, and also from year to year in particular places: these are permanent disabilities of the magnetic compass.

On submarines the state of affairs is even worse. Inside the steel frame of a submarine the magnetic compass does not function at all. Without the gyro-compass it would be impossible to steer a submarine when it is submerged; indeed, the gyro-compass was originally developed for use in submarines.

There is plenty of room in a ship or a submarine to set up a gyro-compass with sufficient stability to give good readings. The compass is swung on gimbals so that it is always horizontal. The axis of the flywheel is allowed to move horizontally only, so that it gives horizontal readings. The flywheel is rotated by means of an electric motor.

The gyro-compass is now mounted on aeroplanes, in addition to the directional gyro.

The Artificial Horizon

There is another kind of directional gyro in which the flywheel rotates horizontally; the axis is of course vertical. This instrument is called the *artificial horizon*; it is used to give a permanently horizontal line. The flywheel is set spinning with its axis vertical, and it goes on spinning with its axis vertical. There is a dial in front of the gyroscope with the tail view of an aeroplane (Fig. 28). The horizontal bar runs across the dial.

A pilot, looking at the instrument, sees the aeroplane on the dial move in the same way as the real plane. If the model tilts up to the left above the artificial horizon, the pilot knows that his plane is tilting in that way. If his plane is climbing he sees the model plane above the artificial horizon; if it is gliding down he sees the model below the artificial horizon. Thus, the pilot can tell at a glance how his plane is trimmed. This is particularly useful when he is flying "blind", through a cloud for

example, where he cannot see the real horizon, or when he is flying in the dark.

Fig. 28.

The purpose of the gyroscope is to keep the bar across the dial horizontal (Fig. 29). The flywheel is housed in a case, which of course swings with it. A guide pin is attached to the housing; it is at right angles to the vertical axis, and therefore remains permanently horizontal. The guide pin passes out through a curved slot in the gimbal ring, and through a slot in a lever. This lever is pivoted at the back of the gimbal ring; at the front it is attached to the horizon bar, and keeps it hori-

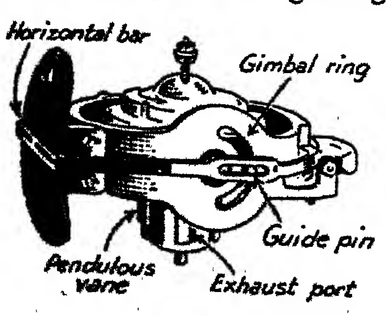


Fig. 29.

zontal. It also communicates to the bar movements of the gimbal ring relative to the flywheel, and so causes the bar to fall when the plane is climbing, and to rise when the plane is gliding down.

Verticals not Parallel

The gyroscope of the artificial horizon is set spinning with its axis vertical, and it would serve its purpose admirably if the axis were to remain vertical. Unfortunately it does not remain vertical, unless something is done

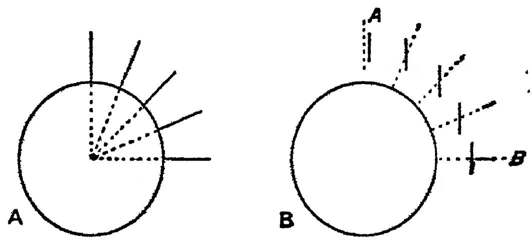


Fig. 30.

about it. The trouble about vertical lines is that they are not parallel; all vertical lines point downward to the centre of the earth; a plumbline hanging freely gives a vertical line and points down to the centre of the earth. Fig. 30A shows vertical lines at various points on the earth's surface, from the equator to the pole. They all point toward the centre of the earth, and so no two of them are parallel. It may readily be seen that there is an angle of 90° between a vertical at the equator and a vertical at the pole; there is the same angle between the verticals at any other two places 90° apart on the earth's surface. Usually the angle between verticals does not bother us, because we are only dealing with places a few yards apart, like the upright walls of buildings. But aeroplanes fly across great distances, and the angle between one vertical and another becomes important.

In an hour an aeroplane may travel 200 miles or more. Now the distance from equator to pole is something over 6000 miles. It is a very easy sum to find the angle between

verticals 200 miles apart. For 6000 miles the angle is 90°, so for 200 miles it is $\frac{200}{6000} \times 90° = 3°$. After travelling 200 miles in any direction the axis of the gyroscope would be 3° out of the vertical; after 400 miles it would be 6° out of the vertical, and the error would go on mounting up. Fig. 30B shows verticals converging toward the centre of the earth, and cutting across them parallel lines representing the direction of the axis of a gyroscope. Notice how the angle between vertical and axis increases from *A* to *B*.

Keeping the Vertical

The double stream of air which keeps the flywheel rotating passes down and pours out through four slots, or ports. When the axis of the flywheel is vertical each of the ports is partly covered by a hanging vane. The four streams of air rushing out from the ports balance each other in pairs, and so have no effect on the flywheel.

Suppose the axis becomes tilted to the right. Two of the hanging vanes swing out of the vertical. The ports are so arranged that one is partly closed by its vane, whilst the opposite port is opened more than normally. The reaction of the out-flowing air is thus increased on one side, and the gyroscope will precess until the axis is again vertical.

The vanes which affect this adjustment are hung from the same spindle and act together. The other pair act in a similar way to check any movement out of the perpendicular in a fore-and-aft direction. When the axis resumes the vertical direction the vanes hang straight down, the ports are equally open and once again there is a balance.

The artificial horizon works correctly in most conditions. During a turn, however, the vanes are swung outward, even though the axis remains vertical. The ports are unequally opened and the streams of air which flow through them begin to change the direction of the axis. Fortunately the effect is not very great, and the axis does not depart more than 5° from the vertical. This is not a dangerous error during the short time that a turn takes,

and the gyroscope soon recovers its correct readings when straight flight is resumed.

The Automatic Pilot

The most spectacular invention which depends on the gyroscope is the automatic pilot. This astonishing instrument, which flies a plane more accurately than a human pilot can fly it, consists essentially of two gyroscopes. The automatic pilot is intended chiefly for level flight, so both gyroscopes have their axes horizontal, in order to check movement out of the horizontal. In one gyroscope the axis runs fore-and-aft, that is from front to back of the plane. The other has its axis athwartships, or across the plane in the direction of the wings.

The fore-and-aft gyro preserves steady forward motion. Any tendency to climb or to dive down would change the direction of the axis; such a tendency is instantly checked by the gyro. The athwartships gyro keeps the wings of the plane level; any tendency of the plane to tip up at one side or the other is instantly checked.

How the Automatic Pilot Operates

Let us see how one of the gyros operates so as to control the movements of the plane. If we understand one of the gyros, then we understand both, since both act in the same manner. We will look at the gyro which checks motion out of a forward straight line.

The flywheel is as usual mounted on gimbals, so that it can swing freely within the outer casing. If the plane begins to swing round to the right, the axis of the gyro moves, relatively to the plane, round to the left. The outer gimbal ring in particular, which can only move to right or left, moves round to the left.

A lever connects the outer ring to a small motor which operates the rudder. A movement of the ring (relative to the plane) moves the lever. The other end of the lever moves so as to open a valve which admits compressed air to the motor. The piston is driven forward; it turns the rudder in the direction opposite to the turn of the aeroplane,

and so brings the plane back to its straight-line course. A swing of the plane in the other direction would open the valve so as to admit compressed air to the other end of the motor, and turn the rudder in the opposite direction.

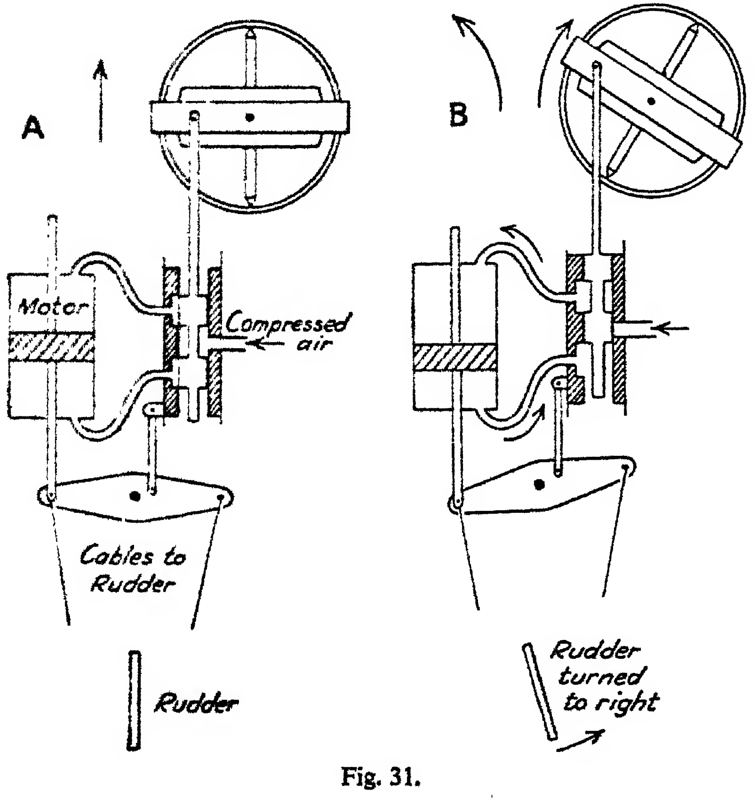


Fig. 31.

Telling the Rudder

The rudder has to be told, as it were, how much to turn. If we were simply to admit compressed air to the motor, the piston would be driven out to the full extent of its stroke, and the rudder would get a full turn. That is not at all what we want: in trying to correct a small turn to the right we should be introducing a much greater turn to the left. In order to avoid this there has to be a double connection between gyro and rudder.

The piston of the motor is attached to the end of a lever which moves the rudder; that is the first connection. On the other side of the pivot of the lever is the second connection. This is a link between the valve and the lever which moves the rudder; it is joined to the body of the valve, and not to the sliding part which is connected with the gimbal ring; it is called a *follow-up link.*

In Fig. 31A the various parts of the mechanism are shown; the plane is going straight ahead. The valve is shut at both sides; the piston is at the mid-point of the cylinder; the rudder is straight behind. In Fig. 31B the plane has veered to the left. The gimbal ring has moved forward; the valve is open, and admits air to drive the piston backward; the rudder lever is pushed back on the left, and the rudder is turned to the right. Thus the veer to the left is corrected. Fig. 32 shows the effect of the follow-up link. The body of the valve is pushed out by the link and the valve is quickly closed.

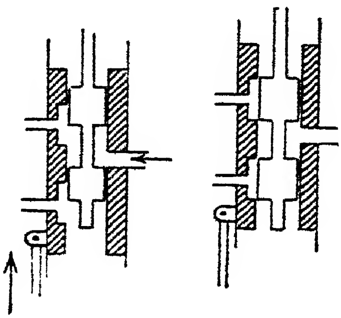


Fig. 32.

The inner gimbal ring can move up and down only. It is connected to the elevators, and controls them in the same way that the outer ring controls the rudder. It checks any tendency to climb or dive. In very much the same way the athwartships gyro controls the ailerons; it causes them to rise on one side and fall on the other, so as to check any tendency to tilt up on one side or the other.

The automatic pilot can be set to control other kinds of flight besides horizontal flight. Before rotation is started, the axis of the fore-and-aft gyro can be tilted up at a small angle, so that it will control a long climb of 5° or less. The axis can also be turned down so as to control a long downward glide of 10° or less.

So long as flight is steady and in a straight line the automatic pilot will do the work of piloting in an efficient way. The human pilot comes on the scene as soon as thinking

is necessary. Turns, sudden climbs, and other manœuvres need the human touch.

Other Uses of Gyroscopes

We have not got to the end of the uses to which gyroscopes have been put or may be put. They have been used to reduce rolling in small ships. Oddly enough, the first attempt to use the gyroscope for this purpose was a failure. The gyroscope was fixed rigidly to the ship, and instead of reducing the rolling it started the ship racketing. It was not till the gyroscope was swung freely, and thus allowed to precess, that it had any effect in reducing rolling.

We have seen how the rotation of the earth can cause precession in any gyroscope. The turning of an aeroplane equally causes precession in all gyroscopes on board. In most of the gyroscopes this is no more than a nuisance. In the rate-of-turn indicator, however, the precession effect is used as a means of indicating at what rate the aeroplane is turning. The greater the precession the quicker the rate of turning.

The monorail is a form of gyroscopic railway in which a single rail is used. This form of railway has been shown to be experimentally sound; trains have been run successfully on a single rail suspended above the ground. The carriages are carried on wheels which rest on a single rail; they are held in stable equilibrium above the rail by rapidly rotating gyroscopes. The special advantage of the monorail is that there is no need to level the ground, or to build expensive bridges. All that is necessary is to have a single cable drawn taut across the region, however rough it may be, over which the trains are to be run.

The "Pull" of the Pole Star

In motor cars, in marine engines, in aeroplanes, there are rapidly rotating flywheels, some of them of enormous size. Almost every kind of machine has some rapidly rotating parts.

One is tempted to ask: why do not all these rapidly rotating parts set with their axes parallel to the axis of the earth?

If they did set in this way they would point to the Pole Star, which stands high above the North Pole. Any clear night we can see the Pole Star if we look to the north. Why do not the axes of all rotating flywheels point to it?

The answer is rather extraordinary, and it may be startling to some people: they try to. The spin of the earth presses on every rotating thing so as to compel its axis to point to the Pole Star. It is only restraining axles that prevent the whole lot of them pointing to the Pole Star.

And it is only round the Pole itself, where the spin of the earth is zero, that axles have no such tendency, and the gyro-compass ceases to function.

2.—STEPS TO THE CINEMATOGRAPH

CAN you answer these questions?

What is persistence of vision?
How can you see through a fence?
What are the ideas the cinema is based on?
How does the cinema book work?
What is the zoetrope?
How can colours be combined?
What invention made the production of the cinema easier?
What is intermittent movement?
How is intermittent movement obtained in the cinema?
What is the use of the shutter in a projector?
Why do wheels sometimes appear to move backward in a film when we know they are moving forward?
How are film cartoons made?
How are drawings made for cartoons?
What is a double exposure?
How are stereoscopic films made?
How are slow-motion films made?
How are processes speeded up on the screen?
What is a colour filter?
How is the sound track on a film produced?
How is the sound track changed back into sound?

THE cinema came not from one toy, but from several, all based on the same ideas. The toys, and the ideas on which they are based, were well known long before the actual cinema was produced.

Persistence of Vision

The first of the ideas is this: if you look at an object, and then shut off all light from it, the image of the object does not fade away at once. It is true that the eye does not hold the image very long after the light is shut off; the time is something like a tenth of a second. But the retention of the image, even for so short a time, is extremely important. Without it, moving pictures would

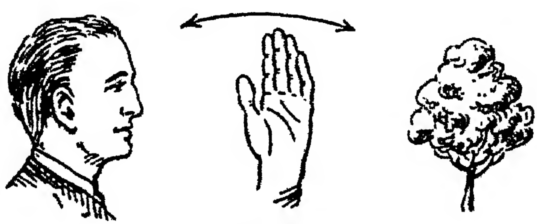


Fig. 1.

be impossible. We call the retention of images by the eye *persistence of vision*.

It is quite easy to show that the eye does retain an image for a short time after the object has disappeared. Close one eye and look steadily at something ten or twelve feet away. Now hold a hand between your eye and the object; light from the object is shut off, and you do not see it (Fig. 1). Move the hand very slowly to and fro between the eye and the object; when the hand is exactly between the two, light is shut off, and you do not see the object. Move the hand more quickly to and fro. When the hand is moved quickly enough the object is visible all the time; light is not shut off long enough for the image to fade completely, and the image persists during the short period that light is shut off.

Measuring a Tenth of a Second

It was by an experiment of that kind that the time during which the eyes hold an image, the time during which vision persists, was measured. Of course great care had to be exercised in measuring so short an interval. A shutter was rotated between the eyes and the object. The shutter was a sector of a circle; it might be, for example, a tenth of the whole circle (Fig. 2). It could be rotated at any speed the experimenter wished.

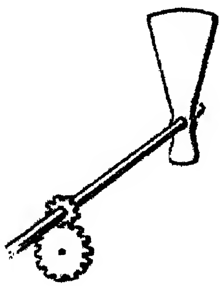


Fig. 2.

As the shutter rotated, light would be shut off for one tenth of the time of each rotation; it would reach the eyes during the other nine-tenths of the time. Suppose we rotate the shutter very slowly, say once in ten seconds. During each rotation light is shut off for one second, and the object is hidden from sight for about a second at each rotation. We speed up the rotation of the shutter, and so reduce the time that light is shut off. We increase the speed to one revolution per second; light is now shut off for a tenth of a second at each rotation. That turns out to be just the limit that enables us to see the object all the time. There is a pronounced flicker, because the object all but fades from view at each rotation. When we double the rate of rotation of the shutter, the object is hidden for a twentieth of a second at each rotation; it half fades only, so that the flicker is much less. By still further increasing the rate of rotation the flicker can be reduced almost to nothing.

Seeing through a Fence

We sometimes see this experiment reproduced when we walk past a fence with small gaps between the palings. When an observer is standing still, the scene behind the fence is almost entirely hidden from him. If he walks fairly quickly, parallel with the fence, the whole scene may be visible in a subdued light. The effect is the same

as if the fence, with its small gaps, were drawn past the eyes like a series of shutters. The light appears subdued because the greater part of it is cut off by the palings. Palings 4 inches wide, with half-inch gaps between them, would cut off eight-ninths of the light.

Seeing through a Wheel

There is an interesting and instructive toy which illustrates the idea of seeing through a fence. We cut out a circle of thin card, about 9 inches in diameter (Fig. 3). We divide it into four equal parts by lines across the centre. On each of the four radii we draw narrow oblongs: measure half an inch in from the circumference for the outer end, then 1½ inches for the length of the oblong. The width of the oblong is a bare quarter of an inch. We then cut out the oblongs, so as to make narrow slots. I find it a good plan to cut through on the lines with a knife, and then to complete the cutting with scissors; this method gives sharp edges.

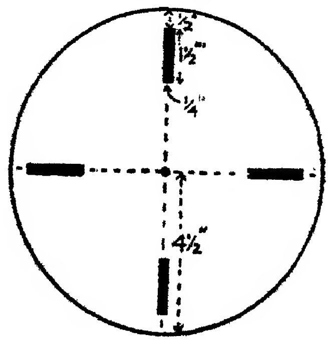


Fig. 3.

We push a thick round nail through the centre of the card, hold the card upright before the eyes, and give it a gentle spin. The scene behind the card comes into view in a subdued light. When the spinning is slow there is a pronounced flicker. The flicker becomes less and less as the spinning becomes quicker.

I have just been holding the rotating disk before a mirror, and looking at its reflection through the disk. To my surprise I saw eight slots on the reflection. I could not for the life of me see why there should be eight, and not four, until it occurred to me to close one eye. Then I did see four slots. Before that I was seeing four with one eye and four with the other.

There is another way in which we can sometimes see objects that are partly hidden. A wheel may almost

entirely block the view when it is still, but when it rotates fairly rapidly the scene behind it becomes visible in a subdued light.

The Illusion of Movement

The second idea on which the cinema is based is this: we can have a number of pictures showing successive stages of a movement; and we can put these pictures, one after another in proper order, before the eyes; when this is done the eyes have the power of putting the pictures together, running one into another, so as to give the illusion of movement. That is not at all an easy thing to do. It was not too difficult to make toys that would work quite well. It was a much more difficult task to throw pictures on a screen in rapid succession, so that they could be seen by a large body of spectators.

The First Cinema Toy

One of the simplest toys involving the cinema idea, or rather one of the cinema ideas, may be made from a post-card, or from an oblong of stout paper (Fig. 4). We draw a line across the middle of the card, making the measurements with some care; then we stretch a piece of string along the line, and paste a strip of paper over it to hold it firmly in position. The string should extend three or four inches on each side of the card. In the top half of the card, and near the middle, we draw a bird; we may paint the bird lightly with blue or red. We give the card a half turn on the string, so as to bring the bottom edge to the top, and the blank side uppermost. In the same position as that occupied by the bird on the other side, we draw a cage with thick firm lines. That completes the toy.

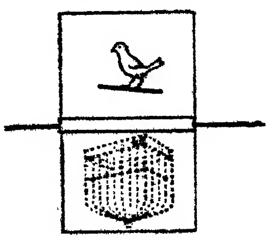


Fig. 4.

We hold the card with the string stretched out at the sides, and we twirl the string rapidly between the fingers.

Looking at the upper half of the card, we see the bird enclosed in the cage. The eyes retain the image of each picture long enough to enable us to see both pictures at once.

Other pictures may be used instead of the bird and cage (Fig. 5): a fish and a glass bowl, a bunch of flowers and

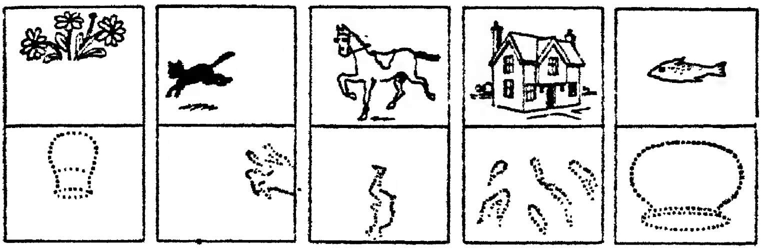


Fig. 5.

a vase, a dog chasing a cat (" Why did the cat run? "), a horse and rider, a house and red-coloured flames, and so on. Some of these double pictures would have to be very carefully spaced and drawn on the card in order to get good effects. We can use the remaining spaces on the card for a second double picture.

Cinema Books

The eyes see no movement of the objects in the toy described above; the toy involves a simple application of the persistence of vision, and that is all. In the next toy the figures actually do appear to move, so that we get a much nearer approach to the cinematograph. The toy is a small book the pages of which are intended to be flicked under the thumb, so that they are seen in rapid succession one after another (Fig. 6). The pictures represent successive stages of some simple action.

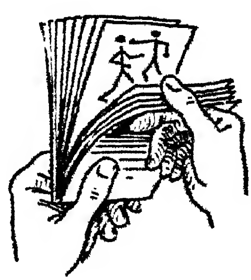


Fig. 6.

A small cinema book of this kind can be very easily made.

Cut up a sheet, or several sheets, of white paper into pieces about 1 inch by 2; fold these over and pin or stitch them down the centre. This makes a book with pages about an inch square. On the inside of the first leaf—that is, on page two—draw a simple picture; then turn over one leaf and draw the second picture on page four. If we hold the first two leaves together in front of a light or against a window pane, the first picture will show through the paper, so that we can get the second picture, which should show the second stage of some simple action, in the correct position. The second picture helps us with the third, and so on to the end of the book, each picture

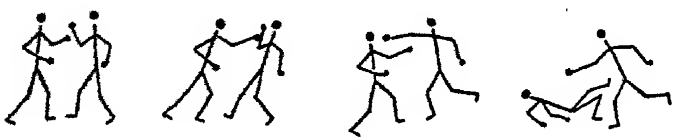


Fig. 7.

showing the action one step further advanced from that preceding it. When we have got to the end we can turn the book upside down and draw a second set of pictures on the left-hand pages.

We may note in passing that the device of holding the drawings up to the light on the window pane is very much like a device actually used in making film cartoons.

"Matchstick" men are easy figures to draw. They may be engaged in boxing, or some other simple series of actions (Fig. 7). We have to be careful not to make too great a difference between one picture and the next. For example, if an arm is being drawn back, three or four positions of the arm may be shown, each a little farther back than the last.

In another form of this toy the picture was viewed through an eyepiece, very often a magnifying glass. The pictures were on a series of cards which were allowed to drop one by one in front of the eyepiece.

The Zoetrope

Still another form of the cinema toy was the zoetrope, so called because living things were often represented in it. A series of pictures, representing different stages of some simple movement, were drawn side by side on a strip of paper. The strip of paper was fixed on the outside of a cylinder so that the pictures faced outward. They were viewed through a small hole, so placed that only the picture opposite the hole could be seen. The cylinder was then made to spin, and the whole series of pictures could be seen, one after another, in rapid succession. Thus the illusion of movement was produced. The best pictures for this toy are those in which the series of actions can be repeated over and over again, the last picture on the cylinder joining on again to the first. The set of pictures represents a single cycle of movements. On the completion of one cycle the next cycle is ready to begin. Walking or running movements were often used in the zoetrope. A jumping frog was popular.

Making a Zoetrope

A simple and quite effective zoetrope may be made in the following way. We cut out a circle of stout card-

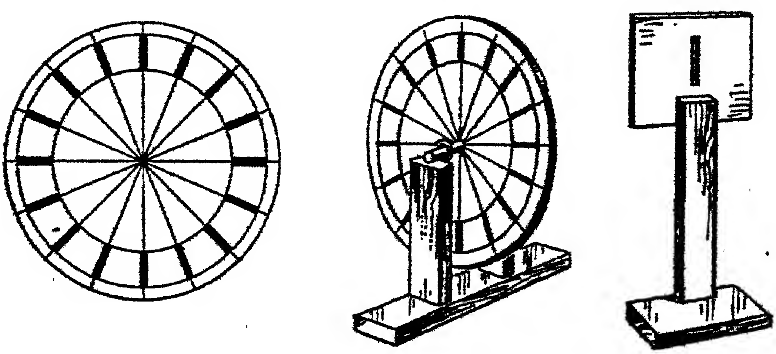


Fig. 8.

board about a foot across (Fig. 8). We draw two circles on it, with the same centre as the cardboard circle; the

radii are $5\frac{1}{2}$ inches and 4 inches. We divide the circle into sixteen parts by equally spaced radii. In the sixteen spaces we draw pictures representing some simple movement; we have to take care to place the pictures evenly in the middle of the spaces. On the lines between the pictures we cut clean narrow slits about a quarter of an inch wide, and the depth of the picture spaces—$1\frac{1}{2}$ inches.

We mount the circle of cardboard on a wooden rod through the centre; the rod is about 3 inches long, and the card is attached to it firmly with strips of paper, gummed or pasted on both sides. We make a small wooden stand, with two uprights close together, say an inch apart and $6\frac{1}{2}$ inches high. We fix steel eyes in the tops of the uprights; the wooden rod should just slip into them, and the card should turn easily when it is made to spin. (It is convenient to have a small hook instead of one steel eye.)

We now want another piece of cardboard, about 4 inches square. On a middle line we cut a narrow slit about 2 inches long. We mount the card with the slit vertical and at the same height as the topmost slit in the circle.

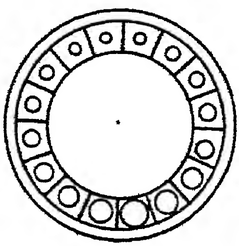
To use the zoetrope we place the picture circle before a mirror, with the pictures facing the mirror. We place the other stand behind it. We look into the mirror through the slit and one of the small slits in the circle. When the card is made to spin, the pictures, seen one at a time in rapid succession, give the illusion of a moving picture. The quicker the spin, the more lively is the movement.

The Simplest Form of Zoetrope

Anyone who has difficulty in producing a good series of drawings can get a simple effect in this way (Fig. 9). Draw a small circle in the first space, a larger in the next, and so on up to the ninth space; then draw decreasing circles, down to the original size. The circles may all be painted the same colour, or we can experiment by painting them alternately blue and yellow, and so on. The radii of the circles may be: $\frac{3}{4}$ inch, $\frac{11}{16}$ inch, $\frac{5}{8}$ inch, $\frac{9}{16}$ inch, $\frac{1}{2}$ inch, $\frac{7}{16}$ inch, $\frac{3}{8}$ inch, $\frac{5}{16}$ inch, $\frac{1}{4}$ inch.

We can get an interesting effect by spinning the cut-out

circle on a large nail, with the drawn circles facing a mirror. The whole of the circles may be seen rapidly increasing and decreasing in size. We can also watch an outside scene through the spinning circle. We may note that it is much brighter than when we have only four slots to see through. We get the same flicker when the speed decreases. It is amusing to keep the disk spinning, just at the flicker point, with gentle taps of the finger, and to watch people and buses go by. It is for all the world like watching one of the old flickering films.



There are numerous other things we can do with this interesting toy. If we stand well back from the mirror and spin the disk, we can see the sixteen slots clearly in the mirror; they appear motionless unless we move our eyes from side to side. If we hold the disk close to the mirror

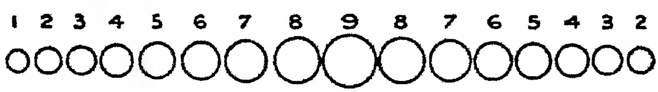


Fig. 9.

we can see fewer slots, and the lower ones appear curved.

If we draw a small circle just inside the circle of slots and fill it in with ink, then we can see several images of the small circle when the disk spins. Careful observation will show that the images in front are clear, while those behind are more and more faded.

If we draw four evenly spaced circles, like the previous one, we can see sixteen circles in the mirror; and they appear to vibrate when the disk is spinning.

Persistence of Colour Vision

Persistence of vision occurs with colours as well as with the outlines of objects. If we present to the eyes blue disks and yellow disks in rapid succession, the eyes see both colours at once: perhaps the blue disk just presented

to them, and the fading image of the yellow disk just removed; then a yellow disk, and the fading image of a blue disk; and so on. If the alternation is quick enough several disks may be seen at once. The eyes see a mixture of blue and yellow, and this gives the effect of green.

There is a very simple way of mixing colours, so that the effect of mixing them may be seen. We cut out a circular disk of cardboard, about 4 or 5 inches across. We paste pieces of coloured paper on the disk, and then spin it on a nail through the centre. Blue and yellow would give green; blue and red would give purple; red and yellow would give orange.

The colour disk explains a very important point about coloured moving pictures. Suppose we have a scene coloured blue, yellow and green in different parts. We take one set of pictures showing the blue parts only, and another set showing the yellow parts only. The green parts would appear in both sets. Then if these pictures were presented to the eyes—blue, yellow, blue, yellow, and so on—in rapid succession, persistence of vision would enable us to carry blue parts over to the next blue parts, and similarly with the yellow parts. The blue and yellow of the green parts, rapidly alternating, would give the green effect.

The Inventor's Problem

The ideas about moving pictures which we have been considering—persistence of vision, the running together of pictures to give the illusion of movement, and the combination of colours—were well known long before the first cinematograph was produced. We have seen that they had actually been used in a variety of toys.

The problem before the inventors of the cinematograph was clear enough: how to throw a series of pictures on a screen in rapid succession, hold each picture in place long enough for it to be seen, and then rapidly to move it out of the way to make room for the next picture. There was also the very similar problem of taking the pictures.

The introduction of celluloid film for taking photographs greatly simplified the problem. The film could be made in

long strips which could be wound on reels; this solved the problem of having the pictures conveniently arranged in a sequence for throwing on a screen. If there had been no celluloid film, paper film could have been used, but celluloid is more convenient to deal with, and it gives a brighter picture on a large screen.

Intermittent Movement

What the pioneer of the cinema had to find was a means of producing intermittent movement: jerking a picture into place in the gate of a projector, so that it could be projected on a screen; holding it there for a short time so that it could be seen; then jerking it out of the way again, and at the same time jerking the next picture into the gate of the projector. It involved a series of extremely rapid movements, with pauses between while the pictures were on the screen. Moreover, it was desirable that the actual movement should not be seen: while one picture was being jerked on to the screen and another jerked off, all light should be cut off.

The usual way of getting the intermittent movement is by means of a *maltese cross* arrangement. Look at the drawings of this device (Fig. 10). A is a wheel which can be rotated at any suitable speed. B is a raised cam on this wheel which goes about five-sixths of the way round the wheel. C is a raised pin on the wheel. The curved edge of the maltese cross fits on to the cam, so that the cam can slide past it.

Now imagine the pin-wheel A rotating in a clockwise direction. At first the maltese cross does not move; the

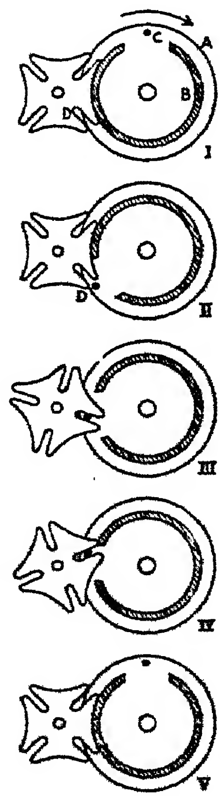


Fig. 10.

cam slides past it. Then the pin C reaches the slot D in the cross; it enters the slot, and presses the cross round as it continues to rotate; the gap in the cam allows the cross to move when half of the curved edge is free. Then the pin slides out of the slot, the cross is again held, and the next rotation begins.

It is not hard to follow these movements when they are performed very slowly. Now we have to think of them speeded up till the pin-wheel revolves sixteen times per second. The sequence of movements is exactly the same, except that they are performed much quicker. The upshot is that the maltese cross receives sixteen forward jerks in each second; between the jerks it is still.

Jerking the Film

That is exactly the kind of intermittent movement we want for moving pictures. We now want a way of transmitting the jerk-stop-jerk-stop movement to the reel of film. On the same axle as the maltese cross there is a sprocket wheel with two circles of sprockets or pins (Fig. 11). The edges of the film are perforated with small holes which correspond with the sprockets in size and position, so that the film can be threaded over the sprockets.

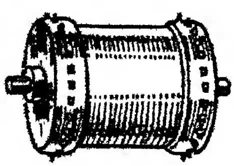


Fig. 11.

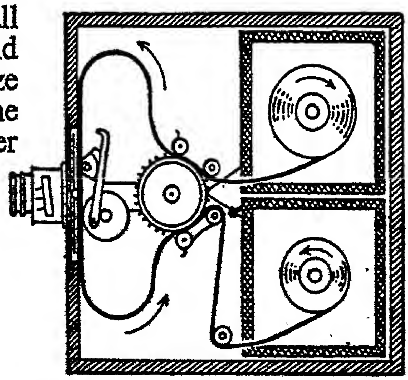


Fig. 12.

The maltese cross begins to rotate intermittently. Each time it jerks forward, the film is jerked forward with it; that is, the film receives sixteen forward jerks per second. The diameter of the sprocket wheel and the distance between the sprockets are measured out so that each jerk draws a

picture into the gate of the projector, and of course draws the previous picture out of the way (Fig. 12). As the pictures pass through the projector they are wound up on another reel. We may notice in passing that before a reel of film can be used again it must be rewound; otherwise the picture would appear to move backwards on the screen. People would walk backwards. If they happened to be eating, or rather uneating, they would take food neatly out of their mouths so that it could join up again to potatoes and cutlets on their plates. Smoke would neatly collect out of the sky and pass down the chimney. And so on through all kinds of movements, big and small, in a backward world.

The Shutter

The other important point in the machinery of moving pictures is to have a means of hiding the pictures during the small fractions of a second when they are being moved on to the screen and off again. The mechanism is quite simple. A shutter rotates in front of the projector (Fig. 13). This shutter is geared to the pin-wheel, and so it rotates with it. It is so arranged that it shuts off light just at the moments when the pictures are being changed. If the movements were slow there would be a pronounced flicker, but we have already seen how increased speed reduces the flicker till it is not observable.

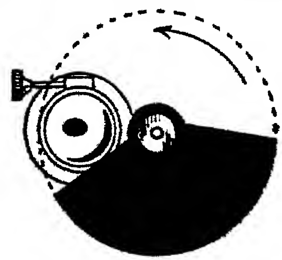


Fig. 13.

Thus it comes about that an observer sees one still picture rapidly following another on the screen. He sees at least two pictures at any time: the picture actually on the screen, and the fading image of the previous picture; if the movement is quick there may be the still more faded images of other pictures. The eyes have the power of sliding the pictures one into another, so as to give the illusion of smooth movement.

The Cine Camera

A cine camera is the projector in reverse. It may even be the same instrument; though it is usual to have details in the camera different from those in the projector, simply as a matter of convenience. In the projector a powerful beam of light passes through the film pictures, and is focused on a screen. In the camera, light from the scene being photographed is focused on the film. The apparatus for moving the film and for shutting off light at the appropriate moments is the same in both projector and camera. The chief differences of construction lie in the provision of a lamp box in the projector, and in the careful exclusion of light from the camera except at the opening where it is intended to enter.

The Early Cinemas

The invention of the cinematograph is definitely ascribed to Edison; the date was 1894. In the original apparatus the picture could be seen by one observer only; but improvements soon made it possible to throw the picture on a screen. In early days the pictures were crude enough, and people went to see them merely for the sake of seeing a curiosity. There were pictures of trains, and soldiers marching, and waves breaking, and so on. Films were used over and over again, until the picture on the screen was blurred and scratched, with sudden flashes here and there; very often the picture jumped about unpleasantly, owing to the wearing of the sprocket holes. In the course of a single lifetime the cinematograph has developed from its crude beginnings in 1894 up to the present perfection of talkies and colour pictures.

The Wrong Kind of Movement

We have seen that the movement of screen pictures is an illusion. Sometimes the illusion is imperfect. A wheel which we know to be revolving rapidly in a clockwise direction may appear to move slowly in an anticlockwise direction. How does this come about? Look at the

much-simplified drawing of a wheel with four spokes (Fig. 14). It is revolving rapidly in a clockwise direction. The first picture is taken with the end of spoke A at the top. When the second picture is taken this spoke has moved to B. Then to C in the third picture, and to D in the fourth. Now the spokes all look alike. We should have the same effect if A moved backward to B_1 then to C_1 and D_1. The eyes seem to select the easiest and slowest movement for their illusion—the lazy way round. Instead of a rapid clockwise movement there appears to be a slow backward (anticlockwise) movement.

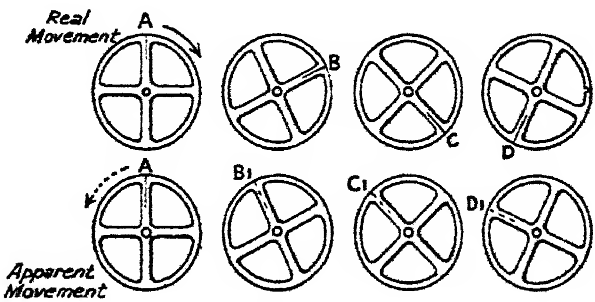


Fig. 14.

If there were distinctive and varied marks on the spokes and rim of the wheel, the eyes would interpret the movement correctly. When the outer part of a wheel is symmetrical and the inner part varied, we sometimes see the correct forward movement in the inner part, and a slow backward movement in the outer part, though we know perfectly well that the wheel is all one, and that both parts are rotating in the same direction.

Film Cartoons

Some of the cinema toys showed pictures of the kind that we now call cartoons. These toys had a series of drawings that gave the illusion of movement when they were presented to the eyes in rapid sequence. The drawings were very simple and they called for no special ability. It was a different matter altogether with the

elaborate drawings that were used to make screen pictures. Just think for a moment of the size of the problem of producing such a picture. Sixteen pictures per second is nearly a thousand per minute, and not far short of thirty thousand pictures for a half-hour run. Thirty thousand complete pictures is a pretty tall order, a truly formidable undertaking. We want to reduce the amount of labour involved in producing a film in every way possible, short of spoiling the film.

In the first place we can divide by two, because each picture can be photographed twice without spoiling the result, indeed with added smoothness. We do not stick exactly to the half reduction. Sometimes we can leave a picture on the screen for half a second or a second before it begins to move; sometimes we can take three or four pictures, instead of the usual two. A little irregularity helps to prevent jerkiness.

How Celluloids are Used

That is of course the biggest reduction that can be made in the number of pictures that have to be drawn. But there are many other ways in which labour can be reduced. As a rule only part of a picture is moving. The background may be still while some of the characters are moving. It would be a great waste of time and energy to draw the still background for every picture. Instead of that we draw a single background on paper. We draw the moving parts on celluloid, and place these in turn over the still background. We may have several celluloids, one over another. In spite of all labour-saving devices, the production of a really good cartoon still entails an enormous number of drawings, and a vast amount of careful work.

When the drawings are being made we have to make sure that each fits exactly into its correct place; otherwise the moving parts will jerk from place to place erratically. The sheets of paper and the celluloids are carefully punched with holes on the upper edge; the holes are the same distance apart on all the sheets.

The Drawing Frame

The method of drawing is very much the same as holding sheets of paper on a window-pane so that light may shine through from behind. The drawing is done on a frame which has a sheet of glass on the sloping top (Fig. 15). Below the glass is an electric lamp which can be used to throw up light from below. The punch holes of one of the sheets of paper are fitted over pegs at the top of the frame; the paper rests on the sheet of glass. A background is drawn on the paper. If any changes are to be made in the background, a fresh sheet can be put over the first one; the light from below enables parts to be traced and changes to be made. Celluloids can be placed over the background, and moving parts drawn on them. The punch holes and pegs ensure that each celluloid goes in exactly the right place. And so the drawing proceeds picture by picture until the cartoon is finished. One group of artists may be working on one part of the picture while other groups work on other parts.

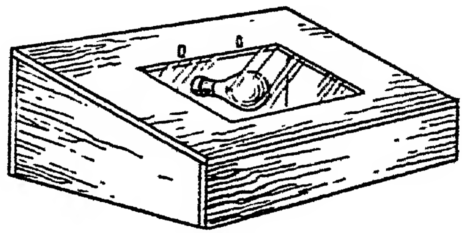


Fig. 15.

You will understand that a lot of preliminary planning is necessary: scheming out the picture; making careful drawings of the backgrounds, and of the characters in various positions, so that these drawings can be used for tracing on to the sheets that will be photographed; and so on.

Repeated Movements

Each drawing is numbered so that the photographers can be sure of photographing them in the right order. When pictures have to be repeated (that is, when the same action occurs more than once) the artist gives the photographer a list showing the order of the pictures and

repetitions: 1, 2, 3, 4, 5, 6, 7, 6, 5, 4, 3, 2, 3, 4, 5, 6, 7, 6, 5, 4, 3, 2, 3, 4, 5, 6, 7, 8, 9, 10, and so on. That list shows an action being repeated three times and then running off into something else. If you watch a cartoon carefully you may be able to detect repetitions that would usually pass unnoticed. In good cartoons repetitions are usually disguised; they do not repeat exactly.

Reversing Scenes

In addition to straight cartoons, many devices are employed to give odd effects on the screen. You may have seen the screen covered with a medley of bits and pieces that looked like nothing on earth. Slowly the bits came together until they looked like a bloated caricature of a famous comedian. Then the bloated parts closed in and gradually formed a portrait of the real comedian, who was talking to you. All very odd when you see it on the screen; and all very simple when you see it being done in the studio. An ordinary film was taken of the comedian talking. The first picture of the film was enlarged and printed on a sheet of elastic. This picture was photographed in the exact position occupied by the original photograph of the comedian. The elastic was drawn out a very little, and pictures were taken; it was drawn out more, and more pictures taken. And so it went on till the photograph was distorted and twisted out of all recognition. Then this film was reversed (simply turned round, so that the distorted part came first instead of last), and it was joined on to the film in which the comedian was speaking. Skilful work ensured that there was no break when the double film was shown as a whole.

Double Exposure

Reversing a film is one simple device that can sometimes be used very effectively; double exposure is another. As in taking ordinary (still) photographs, a certain amount of light must be admitted to the camera. The amount of light admitted may be stopped down to half, and thus a lightly tinted picture may be taken. The exposed film is

taken out, rewound, and replaced in the camera. A second picture may then be taken on the same film with another half exposure. It is by means of this device that we get such extraordinary effects as an actor shaking hands with himself. It is a trick that requires very careful workmanship. On the second exposure the actor has to walk up to the exact spot where he must stand to shake hands; his actions must be exactly timed with a stop-watch and an exact record of the previous times, so that he may move his hands correctly. With the best workmanship small inaccuracies are almost certain to occur. These would show up badly in a simple scene. They can be covered up by arranging the meeting in the background of an elaborate scene, where there is plenty of detail to distract the attention from such inaccuracies.

Another device of the same kind is to expose the right-hand side of the film at one exposure, and the left-hand side at a second exposure. At each exposure half the opening of the camera would be covered up. This method also might be used to obtain the effect of an actor shaking hands with himself. The meeting would have to take place at the junction of the two pictures, and the same kind of precautions as before would have to be taken.

Natural Scenes and Cartoons

Many effective tricks depend on enlarging one picture of a natural scene, and using this as a background for diagram or cartoon work. A mixture of natural scenes and cartoon work is not difficult to produce, but it may entail a lot of work. If you watch such a film carefully you may observe that sometimes the natural scene is moving and the cartoon figures still; at such times the cartoon is merely part of the natural scene, and is taken with it. At other times the natural scene is still and the cartoon figures are moving; in these parts of the film enlarged single pictures from the natural scenes are used as backgrounds for the cartoon. The illusion that natural scene and cartoon are both moving together would not be complete if both were not actually moving together sometimes, even if only for a few seconds. It is these

seconds of double movement that entail much labour. A long stretch of the natural film has to be enlarged and used as a background. Even for a mere four seconds of combined movement the enlarged photographs may stretch a hundred feet or so, and a hundred feet of damp photographic paper takes some manipulating. The cartoon is drawn on celluloids, and photographed over the series of enlarged pictures as a background.

Stereoscopic Films

Many attempts have been made to get a stereoscopic, or solid, effect into films. Something has been achieved by having movement in one direction in the front of a scene and movement in the opposite direction at the back of the scene.

In the ordinary stereoscope two views are taken of the same scene from positions a little distance apart. These views represent the scene as it is viewed by the two eyes separately. Fig. 16 shows the appearance of a small cube as seen by the left eye and right eye separately. We can often perceive these differences when we close first one eye and then the other. Sometimes there is very little difference, but there is usually enough to enable us to see that objects have thickness, and to give a sense of distance. In the stereoscope the pictures are viewed through lenses, so that the right eye sees only the picture on the right, and the left eye only the picture on the left. Thus the scene is made to stand out solidly.

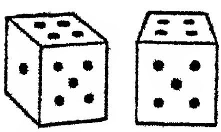


Fig. 16.

This method can be imitated on the screen. Two pictures are taken at the same time by means of a double camera. Then one film is tinted red and the other green. The two views are thrown on the screen together, one being slightly out from the other. The spectators view the screen through coloured glasses, red for one eye and green for the other. Thus the right eye sees only the picture taken on the right, and the left eye the picture taken on the left. The result is a remarkably stereoscopic picture.

Slow Motion Pictures

Extremely slow moving pictures are sometimes shown on the screen. A horse jumps slowly and gracefully over a hurdle. Boxers are seen hitting very slowly, and yet with the effect of swift and powerful punches. In this way the exact nature of their movements can be seen. Indeed such slow-motion pictures have been used to decide doubtful points in boxing, especially when there was a suspicion of a foul blow.

The method of taking slow-motion pictures is extremely simple. The turning of the camera is speeded up; instead of the usual 16 pictures per second, 64 pictures may be taken. These pictures go through the projector at the usual rate, so that they take four seconds to go through. That is, the motion is slowed down to a quarter of what it is actually.

Speeding up Movements

Movements may be speeded up by the reverse process of photographing very slowly. A flower may take 24 hours to open, and we want to show the opening on the screen in a matter of 30 seconds. Now for 30 seconds we want $30 \times 16 = 480$ pictures. We spread these pictures over the 24 hours. We want 20 pictures per hour or two pictures every 6 minutes. In early days a cameraman had to be in attendance to turn the handle every six minutes for the whole 24 hours. Now there is an automatic device which actuates the camera at the proper intervals. It is only necessary to keep the flower illuminated, so that the opening may go on unchecked.

Colour Pictures

We have seen how the eyes can put two (or more) colours together when they are presented in rapid succession. Before using this idea to produce coloured pictures on the screen, we have to be able to photograph the different colours in a scene separately. Fortunately this is not difficult.

When we hold a piece of red glass in front of the eyes all

the world looks red, though some of it may look very dark red and almost black. The red glass lets through red light and stops all the other colours. Thus a piece of red glass can be used as a *colour filter*. If we allowed the red light which comes through to fall on a suitable photographic plate we should have a photograph of all parts of the scene which contain red. White things would appear in the photograph because white contains red as well as other colours. We might be surprised at the amount of red there is in some things we usually think of as green—in spring foliage for instance. A blue colour filter would enable us to photograph the blue parts of the scene, and a yellow filter the yellow parts. Anything white in the scene would appear in all three photographs; purple objects would appear on the red and blue photographs, green objects on the blue and yellow. A very reddish purple would give a dense image on the red photograph, and only a light image on the blue; whereas a bluish purple would give images the other way round. The photographs would indeed show the amount of each colour in each part of the scene. The red photographs for example would be dense where there was much red in the scene and light where there was little red.

How Colour Pictures are Used

Having got the coloured photographs, we can use them in various ways. It is possible to take red, blue, and yellow photographs in sequence on the same strip of film; the colour filters can rotate in front of the camera opening, so as to admit the colours in turn. Prints can then be made in the appropriate colours: red, blue, yellow, red, blue, yellow, and so on. When the film goes through the projector, the different colours are thrown in sequence on the screen. The eyes retain and blend the colours, so as to see the scene in something like the natural colours. The colours are never exact, for many reasons. The colour filters are not perfect. The whole range of natural colours is not reproduced. The dyes used in the prints are not exact reproductions of the natural colours. Those are

some of the reasons why we can only say that the coloured scene on the screen is *something* like the original scene.

In another form of coloured film there were three small pictures on each section of film; one of these was printed in red, another in blue, and the third in yellow. The projector had three lenses, and a beam of light was thrown through each of the three pictures on to the screen. Thus the various colours were reproduced on the screen in their proper places, and a complete coloured picture was produced.

The Talkies

The addition of sound to films did not arise out of a toy, but it may be appropriately referred to here. The early attempts to use ordinary gramophones synchronised to films were more comic than helpful. The synchronisation was always very sketchy and words were spoken at the wrong time, often with laughable results. At any time a break in a film might entail the sacrifice of a few pictures in repairing it; that would throw the gramophone still further out of time. The villain might be uttering the most lofty sentiments while the hero was threatening all kinds of villanies.


Fig. 17.

As usual, the process of getting the *sound track* on to a film is quite different from the process of getting sound from the printed track.

The sound track is a narrow strip down the side of a film. There are two kinds of tracks. In one kind the track is printed black, and it has an uneven edge which represents the sound vibrations (Fig. 17). In the other

kind, the strip is of even width, but its density varies; the sound vibrations are represented by variations of light and shade.

How the Sound Track is Made

We want to see first of all how the sound track gets there. In the first place we have the microphone to change the sound vibrations to variations in an electric current, just as it does in the telephone. The various methods of producing a sound track all begin by changing sound to variations in an electric current.

An electric current can be used to deflect a magnetic needle, as in a galvanometer, and the amount of deflection is proportional to the strength of the current; that is indeed the way in which the strength of an electric current is measured. If the current is continually varying, then the deflection of the needle varies in exactly the same way. And of course a small mirror attached to the needle would vibrate with it.

A narrow beam of light is thrown on the mirror and reflected on to a strip of film on which the sound track is being recorded. The inner edge of the beam moves to and fro with the vibrations of the mirror and so records them on the film. The whole thing of course needs very nice adjustment. The outer edge of the track must be solid black, and there must be room at the inner edge for the whole range of sound vibrations.

Another method of producing the sound track is to feed the electric current, with all its variations, to a special lamp. This lamp is very sensitive; it glows brightly or dully according as the current is strong or weak. The light from the lamp is used to make a print on the film; and so we get a print more or less dense, according to the amount of light, and therefore according to the original sound vibrations. This kind of sound track is uniform in width, and varies in density.

Still another method is to change the electric variations into vibrations of thin iron disks; this method also is used in the telephone, so it was readily available. Two disks are used, very close together; as they vibrate the space

between them widens or contracts with the vibrations. A beam of light is thrown through the space between the disks; and more or less light passes through as the gap is widened or narrowed. This varying (or modulated) beam of light is used to make a sound track of varying density.

Back to Sound

A lot of research and careful work were necessary before it was found possible to produce a sound track that gave satisfactory results. It was comparatively simple to make the change back to sound, because the photo-electric cell was well known.

A beam of light is thrown through the sound track. Both kinds of track allow varying amounts of light to pass through, either by the variable width of the gap through which light can pass, or by the varying density of the track. The modulated beam of light is allowed to fall on a photo-electric cell, and the cell produces currents exactly proportional to the amount of light that falls on it. The varying current is amplified and fed to a loud speaker which changes it back to sound vibrations.

How the Sound Track is Printed

There is another point of interest about sound films. We have seen that a film goes through the gates of the camera and the projector in a series of jerks. Needless to say that would not do at all for the sound track. The sound track has to be recorded smoothly and projected smoothly.

For that reason the sound track has to be recorded separately from the picture film, though there has to be exact

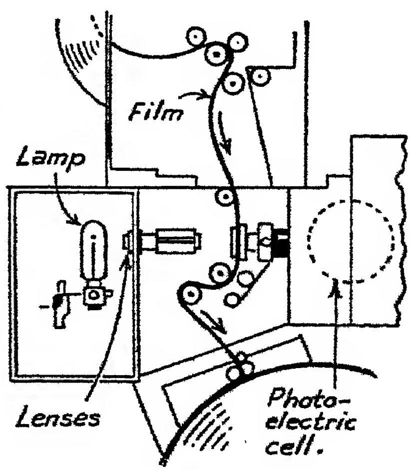


Fig. 18

synchronisation between the two. The sound film runs smoothly through at the same time and rate as the picture film.

There is a very easy solution of the problem of projection (Fig. 18). The film runs through the picture gate with the usual intermittent motion. There is a free loop, and then the film runs through smoothly while light is being changed to sound; the roller which carries it round is geared to the original smoothly turning roller, and not to the intermittently turning one. The loop ensures that the two parts of the film do not interfere with each other.

When films are printed from the negatives, pictures and sound track are both printed in the same film. The sound track has to begin a little before the pictures in order that the two may synchronise when the picture appears on the screen. The difference is the length of film between the picture gate and the sound gate.

3.—KITES AND AEROPLANES

Can you answer these questions?

What controls are there in kite-flying?
How were kites used for military purposes?
How is a box kite made?
How is a toy glider made?
What attempts were made to imitate birds?
Who made the first "aero-planes"?
Why did not Stringfellow's machine fly?
What is the "relative wind"?
What is the "fallacy of the model"?
What invention made flying possible?
What contribution did the Brothers Wright make to the art of flight?
How are aeroplane wings supported?
Why are aeroplane parts streamlined?
What are the chief controls on an aeroplane?
How are the ailerons used?
How are turns made in an aeroplane?
What is "stalling speed"?
What is the stalling angle?
Why are slotted wings used?
How does the constant-speed airscrew operate?
What causes the airman's blackout?
Why is a sharp turn at high speed dangerous to an aeroplane?
Why have airmen been called "*g* men"?

If the grandfather of the automatic pilot, "George", was a spinning top, it is equally true that the father of the aeroplane was a kite.

How to Make a Kite

Anyone who has not made a kite has missed a most interesting job; it is much more interesting to make a kite than to buy one, and the results are usually more interesting too. The materials for a good strong kite, which can be counted on to interest intelligent people, consist of: a piece of thin cane, about two feet long; a builder's lath, thin and an inch wide; good thick flour paste; some strong thick string; and lastly, a couple of sheets of

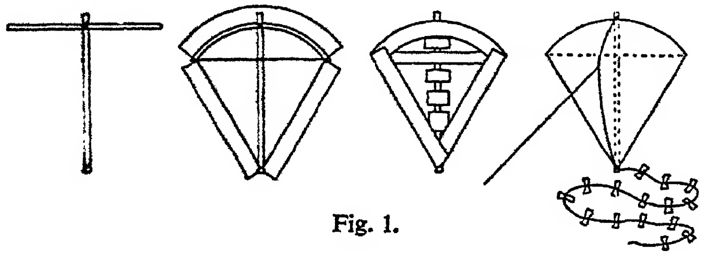


Fig. 1.

newspaper. With these simple materials we can fly the skies.

We cut off a piece of the lath, 2 feet long, or rather more; 2 feet 6 inches is not out of the way (Fig. 1). We cut notches fairly deeply into both edges of the lath; we cut them near both ends and also about 6 inches from one end, but the last-named notches may be cut later on when the cane is in position. We tie the middle of the cane firmly to the top of the lath, using the notches to make it secure. We tie strings from the ends of the cane to the notches at the lower end of the lath; small notches in the cane are a help in making these strings secure. The pull of the strings bends the cane into a curve. We then tie a string across between the ends of the cane. Now is the time to make notches in the lath, so as to have the cross string quite secure. At this stage we hold the framework

of the kite very lightly near the top. It should balance evenly, with the central lath upright. If necessary, make adjustments to ensure that the lath is upright. A kite that does not balance at this stage will not fly evenly.

We lay the framework on a sheet of newspaper, and we cut the paper so that it overlaps a couple of inches all round. We fold down the overlap, and paste it over the string and the cane. We also paste strips of paper over the piece of string which runs across the kite, and over the lath; we want to hold the lath firmly to the paper below it.

The next thing is to bore small holes near the top and bottom of the lath. It is advisable to bore these holes with a red-hot nail, so as to avoid splitting the lath. We thread a string through the two holes, and knot it at the back so that it makes a loose loop in front of the kite.

For the tail we use about 4 yards of string, and tie small rolls of paper to it at intervals of 5 or 6 inches. The tail is attached to the hole at the bottom of the kite.

Kite Control

We should now have a serviceable kite that will fly to a good height, and hold its own in a strong wind. Such a kite can be very instructive.

There are two faults that may prevent the kite taking the air. It may be too heavy; or, what is the same thing, the surface may be too small to support the weight of the kite. We can reduce the weight by cutting off part of the tail. Or the kite may persist in turning over and diving nose downward to the ground. We can perhaps remedy that fault by increasing the weight of the tail, simply tying a small weight to the end of it. Or it may be that the string has been attached too low to the loop which goes across the kite from top to bottom. We can try the effect of pushing the string a little farther up.

Remember that we have two controls in kite-flying: the weight of the tail, which we can add to or decrease; and the position where the string is attached. By experimenting with these controls we can get the best out of the kite, and we can learn a lot about the art of flying. We may notice, for example, that when the wind freshens the

kite begins to flatten out horizontally, and it may nose-dive. In such conditions the usual tail may not be heavy enough. Or we may get stability by raising the string which holds the kite, and so pulling it at a higher point.

Another important observation is this: in a very light wind the kite may stop pulling quite suddenly, and may begin to flutter down out of control. The thing to notice specially is that at a certain wind-pressure the control ends suddenly. We can recover control by running with the kite and so drawing it against the wind. That has the same effect as an increase in the speed of the wind. In fact it is an increase in the *relative wind*, that is, in the movement of the air relative to the kite.

Military Kites

Kite-flying is a very ancient pastime. The Chinese have long been famous as kite-fliers; they made their kites in fanciful shapes, and were expert in flying them. The most important developments in the construction of kites are, however, quite recent. Towards the end of last century men began to think of using kites for military purposes. The idea was that men might be raised so high in the air that they could see out over the enemy's lines, or that cameras might be flown out over the enemy's lines to photograph them. Captive balloons had been used for these purposes, but kites had many advantages over balloons: they were cheaper, more easily transported, they could be brought into action more quickly, and they offered a smaller target to the enemy.

One of the most successful attempts at lifting a man by means of large kites was made by Baden-Powell in 1894. He constructed an enormous kite, 36 feet high, and with this he succeeded in lifting a man. Later on he used five or six smaller kites, attached one above another; these kites were about 12 feet high. The inventor was able to raise himself to a height of 100 feet. Experiments were also made in America and in other countries, and but for the coming of the aeroplane, military kite-flying would probably have developed much farther.

Box Kites

Many attempts were made to improve the construction of kites, some of which were very successful. The most successful of all was the *box kite*, which was invented by Lawrence Hargrave in Australia; it is sometimes called the Hargrave kite, after the inventor. The box kite consists of two oblong boxes (Fig. 2), open at the ends, and placed side by side with open ends facing each other. The boxes are connected by horizontal rods. The kite is flown from a loop of string fastened to one of the boxes.

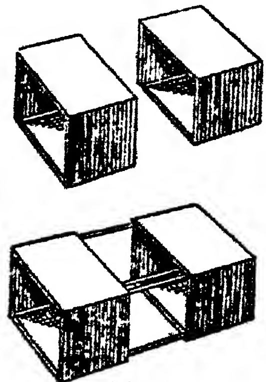


Fig. 2.

Box kites have been much used for making weather (meteorological) observations. Instruments are taken up, automatically make the records, and are then hauled down. For very great heights, however, small balloons are more satisfactory.

Toy Gliders

There are many kinds of small toy gliders. Probably the simplest of them all is the most instructive. Anyone who has not previously made one of these gliders may be

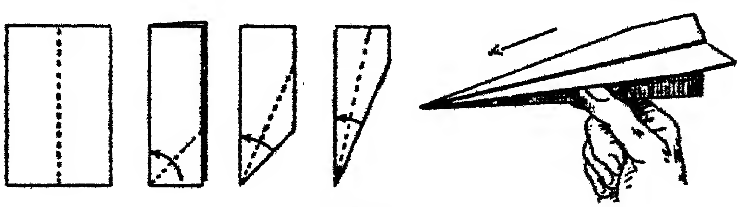


Fig. 3.

surprised at their performances. The only material needed is an oblong sheet of paper, the size of a page of an exercise book (Fig. 3). We fold the sheet in two lengthways. We take up one of the corners, and fold it

over so that the short edge falls on the long middle edge; then turn over and do the same on the other side. Take up the diagonal line and fold it on to the middle line; then fold the new diagonal line to the middle. Repeat on the other side, and press down the folds strongly.

How to Control the Glider

Hold the glider in the fingers, near the point, with the two pointed planes horizontal, and the other part vertical. Give the glider a sharp forward jerk. The pointed front cuts through the air and the horizontal planes support the glider in its flight. Try the effect of throwing the glider back to front. Very probably it turns round so that the point comes to the front, and it may fly upside down. There are other experiments we can try. The back of the vertical plane may be used as a rudder. We give it a bend to right or left, and the glider swings round in the direction toward which the bend is made. A slight bend is all that is necessary; the glider responds to it readily. Then the rear tips of the horizontal planes may be used as elevators. We turn up the tips very slightly, and the glider climbs. We turn the tips down slightly and it does a rapid nose-dive. If we turn one tip up and the other down, they cause the glider to rotate, like a very slow propeller, as it moves forward. In one way and another quite a lot may be learnt about flight by experimenting with this simple little glider.

Imitation Birds

Though men had flown kites for thousands of years, and should have known something about these humble little aeroplanes, yet when they began to think of flying machines it was not kites they tried to imitate, but birds. The earliest stories of flight are obviously myths. Dœdalus, it is said, made for himself and for his son, Icarus, wings of feathers fixed together with wax. Equipped with these wings they tried to escape, by flying, from the island of Crete. But Icarus injudiciously flew too near the sun; the wax melted, and he fell into the sea and

was drowned. That is a mere dream of flight, but it is a dream that persisted until quite recent times.

It is hardly surprising that men should imagine that flexible wings, like those of birds, were indispensable to flight. What is more surprising is that they should think feathers essential, especially as they were familiar with the bat which flies successfully with no feathers at all. There is an authentic story of the early 16th century which illustrates the old illusion about feathers and flight. An Italian alchemist who visited Scotland at that time offered to fly from the walls of Stirling to France. He carefully constructed a pair of wings out of feathers, and with these attached to his shoulders and arms, all ready to be flapped in the wind, he jumped from the walls. He crashed to the ground and broke his thigh. However, he had a ready explanation for his unfortunate accident. It appeared that he had been obliged to use the feathers of barndoor fowls for parts of his wings; it was these feathers, from birds that hardly fly, and that are attracted to dunghills, that had let him down. If he had been able to make the whole of the wings out of eagles' feathers, they would have been attracted to the air, and he would have soared off nobly to France. Said he!

In his romance *Rasselas* Doctor Johnson gently satirises the old attempts at flight by imitating birds: "The artist was every day more certain that he should leave vultures and eagles behind him, and the contagion of his confidence seized upon the prince. In a year the wings were finished; and, on a morning appointed, the maker appeared furnished for flight on a little promontory: he waved his pinions a while to gather air, then leapt from his stand, and in an instant dropped into the lake."

Nevertheless the idea of imitating birds or bats dominated the attempts at flight long after the time of Johnson. It was generally thought that the wings must be elastic, and capable of beating the air in the same way as the wings of a bird. One of the most successful of the artificial birds was that of M. Pénaud which took the air in 1872. This "bird" had a wing spread of a little more than 2½ feet.

It was not capable of rising from the ground by its own mechanism; but if it was liberated from a height it would descend a couple of feet, and then, having got up sufficient speed, it would rise and fly a distance of 50 feet or so. Even this "bird" was no more than a toy. The real problem was to enable men to fly, and M. Pénaud came nowhere near a solution of this problem.

The First "Aero-planes"

The first real advances came just before Pénaud's "bird". In attempting to conquer the air, a few men had given up the idea of imitating birds. They took as their model the kite with its wide expanse of flat surface.

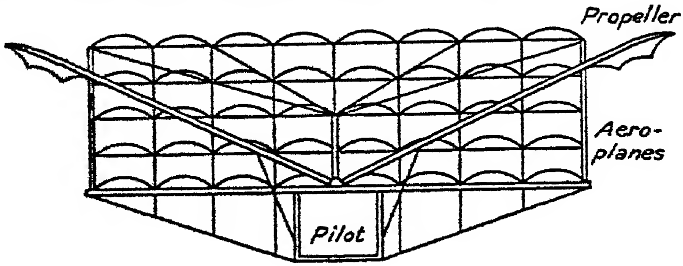


Fig. 4.

In 1867 Mr. Wenham produced a sort of kite, with wings which he called "aero-planes" (Fig. 4). The aero-planes were bands of holland, 15 inches wide and 16 feet long. A man seated in this apparatus was actually raised from the ground by a gust of wind.

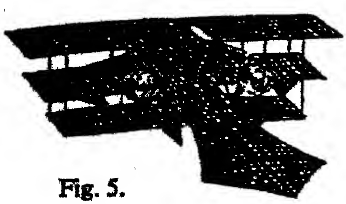


Fig. 5.

In the following year Mr. Stringfellow produced his famous flying machine. This machine had three planes, and Stringfellow had added a tail which was lacking in Wenham's model; the machine was driven by a screw propeller (Fig. 5). It was indeed a near approach to the modern aeroplane, and it may be regarded as the first aeroplane. The chief difficulty was the motive power.

Stringfellow had devised a very light and powerful steam-engine. The whole engine weighed less than 12 pounds, and it developed a third of a horsepower. With this engine Stringfellow's machine was run along a wire at the Crystal Palace. It was said to lift itself occasionally from the wire.

Stringfellow's machine was criticised at the time of its first appearance for what we should now consider its virtues. One objection was that the planes were rigid, and not flexible like those of a bird or bat. The idea of flexible wings for aeroplanes has long been given up. Another objection was that it should be necessary to have so powerful an engine to raise so small a weight. We know now that the engine was not powerful enough.

Kite and Aeroplane

Let us compare for a moment the aeroplane, and the kite from which it was developed (Fig. 6). The great wings of the aeroplane correspond to the flat surface or surfaces of the kite. The kite is supported by the pressure of the wind on its plane surface. We know that the front or leading edge

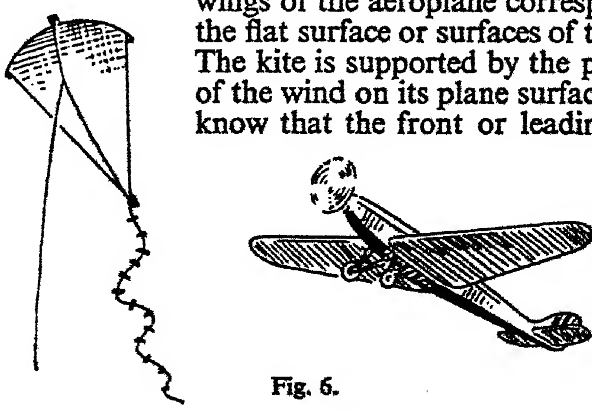


Fig. 6.

of this plane must be kept tilted up; if the rear, or trailing, edge is tilted up the kite at once begins to nose-dive. The leading edges of the wings of an aeroplane must also be tilted up, so that the air strikes against the under surface. The tilt is not great, but it is very important.

We have to understand that a plane pressed forward against the air is supported in the same way as if it were

held in a wind of equal speed. It is the relative movement of plane and air that is important. A plane travelling at 200 miles per hour is supported in the same way as if it were held in a wind of 200 miles per hour—the *relative wind*. This fact is used in the experimental wind-tunnel. An aeroplane is moored in the tunnel, a powerful wind is driven through the tunnel, and the behaviour of the aeroplane in this wind is studied. This behaviour is the same as if the plane were travelling through still air at the same speed as the wind in the tunnel is moving.

The motive force which holds the kite in the air is the pull of the string. This corresponds to the pull of the airscrew which draws the aeroplane through the air. The pull of the string against moving air has the same effect as the pull of the airscrew through still air.

The tail of the kite keeps the centre of gravity of the kite down, and so prevents nose-diving. The weights of the different parts of an aeroplane are so disposed as to have the same kind of effect; they keep the centre of gravity of the plane sufficiently low to prevent nose-diving. The tail also prevents nose-diving.

After that the analogy between kite and aeroplane begins to break down. A kite has no need for the numerous controls that are essential or desirable parts of an aeroplane.

Toy Airscrews

There is one other part of an aeroplane that has its counterpart in a toy; that is the airscrew. We sometimes find in toyshops a toy, costing a penny or two, in which a small airscrew is made to rotate by forcing it along a rod with spiral wires—very much in the way that a bullet or a shell is made to rotate by the rifling in the barrel of a gun. We push the little airscrew upward until it leaves the end of the spiral rod. Then it climbs beautifully upward through the air to a considerable height; it cuts its way through the air just as the airscrew of an aeroplane does. If we turn the little airscrew upside down and push it off the end of the spiral rod, it cuts its way quickly downward to the ground. We can also push the little airscrew

sideways. It travels horizontally, but as soon as it is released it begins to fall to the ground. It should be clear that the toy airscrew has the same sort of pull as the airscrew of an aeroplane.

All the parts of an aeroplane were in existence before i was possible to fly an aeroplane; they were all known a toys. In addition to this, Wenham had devised hi: "aero-planes" that had actually lifted a man; String fellow had added a tail to his flying machine, as well a: rigid planes. And the use of the airscrew as a propelle: was well known.

The "Fallacy of the Model"

There was no great difficulty in persuading a smal model aeroplane to fly. As we all know, successful model: can be flown a considerable distance by means of a strip o: twisted elastic. But a machine that will work perfectl} as a model may not work at all when the size of the machine is increased.

The model aeroplane is an interesting example of the "fallacy of the model" (Fig. 7). It is an example alsc which is easy to understand. Suppose we have a model biplane with a wing spread of a foot, and wings 2 inches wide. The area of both wings together is $2 \times \frac{1}{6} \times 1$ square foot $= \frac{1}{3}$ square foot. The weight of the whole model may be 4 ounces. Four ounces is supported b} $\frac{1}{3}$ square foot of wing. At the same rate a square foot o] wing would support 12 ounces.

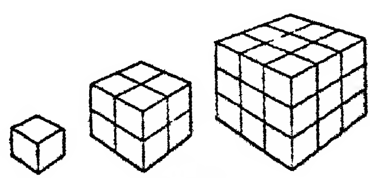


Fig. 7.

Now let us use the toy as a model for a much bigger plane. We use the same kinds of material tc construct a plane with a wing spread of 10 feet. All measurements are ten times as great as similar measurements in the model. The wings are 10 feet long and 2C inches wide; the area is therefore not 10, but 100 times as great. $\frac{1}{3} \times 100$ square feet $= 33\frac{1}{3}$ square feet. When we come to volumes we have to remember that length,

breadth and thickness are each 10 times as great; so volumes are $10 \times 10 \times 10 = 1000$ times as great. As we are using the same kinds of materials, weights also are 1000 times as great. The total weight is 4×1000 ounces $= 250$ pounds. Each square foot of wing must carry a weight of $\frac{250}{33\frac{1}{3}}$ pounds, or $7\frac{1}{2}$ pounds. It would take a powerful engine to give that plane sufficient speed to enable it to fly, but a modern engine would raise it easily enough.

Now let us see what happens if lengths are again multiplied by 10. We must keep in mind that areas will again be 100 times as great; and volumes and weights 1000 times as great. The area of the wings is increased to $33\frac{1}{3} \times 100$ square feet $= 3333\frac{1}{3}$ square feet. The weight is increased to 250×1000 pounds $= 250{,}000$ pounds, or over 100 tons. Each square foot of wing surface would have to carry $7\frac{1}{2} \times 10$ pounds $= 75$ pounds. Such a machine would not fly at all. The greatest *wing-load* that a well-designed aeroplane with the most powerful engine will support is not much more than 40 pounds per square foot.

We can see now why Pénaud's " bird " was not a real solution of the problem of flight, and why toy aeroplanes and gliders were so long in advance of full-scale planes.

The Need of Powerful Engines

Stringfellow's engine, which got a third of a horse-power from a weight of 12 pounds, was a wonderful bit of mechanism; but it did not solve the problem of flight. Although it was thought to be unduly powerful at the time when it was made, we know now that it was not nearly powerful enough. Indeed, if we had had to rely on coal and steam, it is doubtful whether aeroplanes would ever have been possibilities. We should certainly not have had aeroplanes of the great weights and enormous speeds that are now commonplace. It was not till the internal combustion engine, run on petrol, had been developed that engines were produced sufficiently small, and at the same time sufficiently powerful, to drive a large aeroplane.

What the Brothers Wright Did

All the time that men were experimenting and attempting flight, they were finding out things about how the air supported flat planes. But even when it was possible to have an aeroplane that would fly, it was still not possible to fly it. The trouble was that there were no pilots; there was not a single human being who had any real experience of flying. If you think of the long and careful training that pilots now undergo, and how much they learn from the experience of other pilots, you may begin to understand the quandary in which the pioneers of aviation found themselves. And you may begin to have an added respect for those pioneers.

Now one of the most important of all lessons is this: the best way to learn how to do a thing is—to do it. That is what the Brothers Wright, Wilbur and Orville, set out to do. They set themselves to find out how to fly—by flying. They began with a glider, starting it from the top of a slope. Afterwards they added an engine, and so flew the first power-driven aeroplane. Their experiences taught them what was necessary in the way of controls. That was their great contribution to the mechanics of flight.

Vortices

At first it was thought that the wings of an aeroplane simply pressed on the air, and that the air flowed along evenly under the wings. Now anyone can see for himself that this is not so. We have all seen the little swirls that come away from the wing-tips of aeroplanes. In certain conditions of the atmosphere the swirls, or *vortices*, which are shed by the wing-tips, cause moisture to condense, and so we get the little spiral clouds that show us how air is moving round an aeroplane wing (Fig. 8).

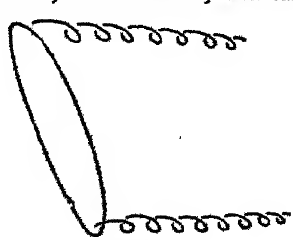


Fig. 8.

Experiments show that there are vortices round any surface that is dragged quickly through the air. The existence of these

vortices is one of the most troublesome things to aeroplane designers, though flight would be impossible without the large vortices round the wings.

How an Aeroplane is Held Up

Above the wing of an aeroplane it has been found that the air stream is moving more rapidly than the relative wind (that is, quicker than the speed of the aeroplane); and so air is drawn out of the space above the wing (Fig. 9). That is, a partial vacuum is produced above the wing, and the wing is therefore driven upward by the greater pressure below. Below the wing the air stream is moving more slowly than the relative wind, and so air is compressed below the wing; this adds to the upward pressure. Thus there is a double lift on the wing, due to the reduced pressure above and the increased pressure below. It has been found that the upthrust due to decreased pressure above the wing is about two-thirds of the whole upward pressure; the remaining third is due to the increased pressure below.

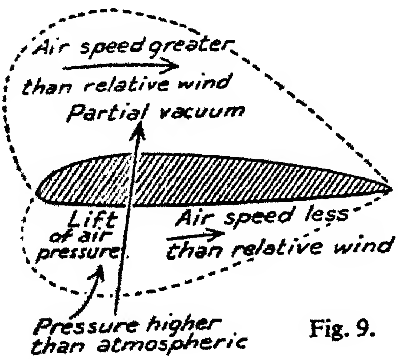


Fig. 9.

The difference between the lesser pressure above the wing and the greater pressure below is the total lift of the aeroplane. This may amount to as much as 40 pounds per square foot of wing area; that is, the total weight (including the weight of the plane itself, its equipment, fuel, passengers, and gear of all kinds) that the plane can lift. Thus an aeroplane may have a wing area of 600 square feet, and a maximum wing-load of 30 pounds per square foot. The total weight it can carry is 600 $\times$ 30 pounds = 18,000 pounds = about 8 tons. If the plane itself weights 5 tons, then it can carry an additional 3 tons of passengers, fuel, and gear of all kinds. If it were loaded beyond that limit it would not leave the ground under its own power.

Modern Improvements

Designers are always trying to increase the efficiency of aeroplanes, and in particular to raise the maximum wing-load, so that a plane can carry a bigger cargo of one kind or another. If you look at a picture of one of the early aeroplanes, you will see that it has a great many wires and struts of all kinds, whereas in a modern plane the wires and struts are very few; every wire or strut that can be done without is removed. A modern plane has a clean

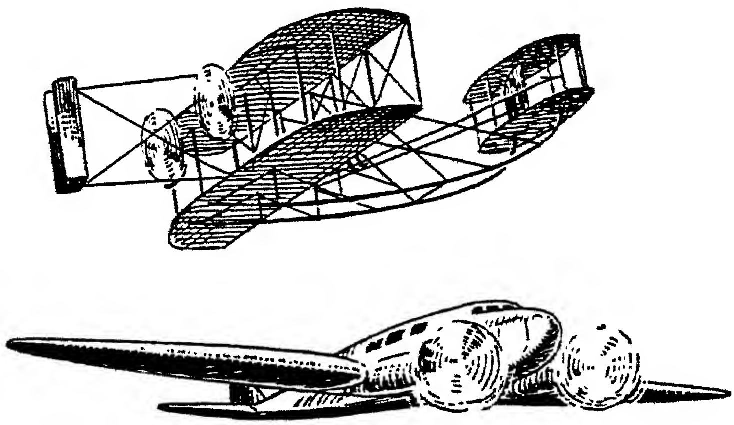


Fig. 10.

design; some of the older ones were fussy in the extreme (Fig. 10).

Now it is by just such improvements as these, from a fussy design to a clean one, that the speed and wing-load of an aeroplane are increased. Every one of the surfaces of an aeroplane has to be dragged through the air at great speed; every one of them uses up a certain amount of engine-power. So the fewer surfaces there are the better.

Streamlines

There is another point to be considered respecting these surfaces that have to be dragged through the air, and we can do a few simple experiments to illustrate it. We can see what happens when a body is dragged through water,

and a similar sort of thing happens in air. Suppose we drag a flat piece of wood, broadside on, through water: it is with difficulty that we can move it at any speed, and we see the water flow in behind it in the familiar vortices. If, however, we hold the wood edge on to the direction in which we move it, it slips through the water quite easily. It is evident that the shape of a thing which is to be dragged through water, or air, makes a great difference to the amount of energy used up in moving it.

We continue our experiments in water. We cut an oblong piece of wood, set it afloat, and give it a forward jerk. It moves forward with some reluctance; the shape is evidently a bad one for an object to be moved through water. We cut other shapes out of wood of the same thickness, so that we can compare the jerks needed to drive them forward. If we keep on experimenting we shall find that a boat shape is the best. Indeed, it was by just such experiments, probably very crude ones in the early stages, that the boat shape was arrived at.

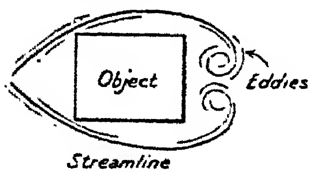


Fig. 11.

While we are experimenting we may notice how the water moves round the floats we are using. We can see the curves it makes, and we can see the swirls of water behind the float. These curves are called streamlines—the lines taken by a stream of water, or air, in flowing past an obstacle (Fig. 11). If we imitate the streamlines in our float, the water will flow smoothly past along these lines, the float will move forward with the greatest ease, and the detaining swirls at the back will be reduced to a minimum.

Whenever we want rapid motion through water or air we resort to the device of streamlining. Boats and ships are always more or less streamlined; so also are fast steam locomotives and racing motor-cars.

Boosting up Speed

Speed is supremely important in aircraft, especially in military aircraft. Nothing is neglected that is likely to

increase speed. The number of surfaces that have to be dragged through the air is reduced to a minimum. Surfaces that are essential are streamlined. The nose of the fuselage is pointed or rounded; the sides are smooth, and follow streamlines as closely as possible. Any necessary struts, and even the few necessary wires, are all streamlined. Every improvement in design, cutting out an unnecessary surface, reducing the size of another, improving the shape of one of the parts, may add a little, even if it is only a mile per hour or so, to the speed of an aeroplane. Thus, by means of numerous small improvements, the speed may be gradually boosted up, without any radical change in design, so that a new type may have an increase of perhaps 25 miles per hour over the previous one.

The Controls

Let us look now at the controls of an aeroplane, the respect in which the plane differs most from a kite; though we have seen that even a kite has some controls. Stringfellow had added the very important tail to his flying machine; like the tail of a kite, it would give stability, and help to prevent nose-diving. But he does not seem to have realised the number of controls that were necessary; he had not got the actual experience of flying that was first gained by the Wright Brothers.

The things we want to be able to do in flying an aeroplane are to climb up, to glide down, and to turn to right or left. If we can do these things then we can move in any direction, and all sorts of complicated manœuvres are possible. In addition, we want to be able to correct any tendency of the plane to tip up to right or left.

The Tail Controls

The tail of an aeroplane has two controls—rudder and elevator (Fig. 12). It actually consists of four planes, two of them vertical and two horizontal. Of each pair, one plane is fixed and one movable. The fixed planes are intended to give stability; the movable ones are the controls. The upright fixed plane is called the *fin*. The

rudder is hinged to the fin at the back, and it can be moved to right or left like the rudder of a boat. The horizontal fixed plane is called the *tail plane*. The *elevator* is hinged to the tail plane, also at the back; it can be moved up or down. The elevator is usually in two parts, one on each side of the rudder. There may be a single rudder in the middle, or twin rudders, one on each side of the tail plane.

Let us see how the rudder works. Suppose it is turned

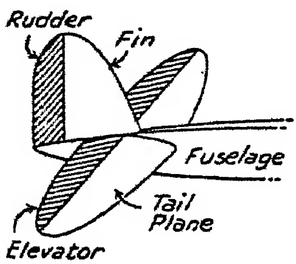


Fig. 12.

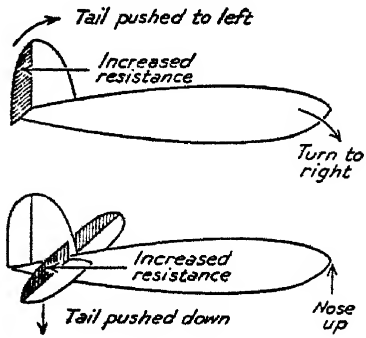


Fig. 13.

to the right (Fig. 13).; then the air—pressing on the rudder—pushes it round to the left, and so the nose of the plane swings round to the right, that is in the direction toward which the rudder is turned. Similarly, to turn to the left the rudder must be moved over to the left.

Now let us raise the elevator (Fig. 13). Air pressing on the raised elevator forces the tail down. The nose is thus raised above the tail, and the plane begins to climb. When the elevator is lowered, air pressing on it below forces the tail up. The nose is now below the tail, and the plane begins to glide down.

The Ailerons

So far there is nothing greatly different from the steering of a boat. But in turning a boat, the mere moving of the rudder to right or left is sufficient; the resistance of the water is enough to prevent a side-slip. If we were to attempt to turn an aeroplane merely by using the rudder

there would be a serious side-slip. Air is an elusive thing, and its resistance is not sufficient to prevent the slip. It is, therefore, necessary also to bank. We have all seen an aeroplane turn with the outer wing raised, and the inner wing lowered. That is what we mean by banking, and in order to bank we have to use the *ailerons* (Fig. 14). The ailerons are flaps on the rear or trailing edges of the wings. The controls are so arranged that when one aileron is raised the other is automatically lowered. Suppose we raise the aileron on the left; at the same time we lower the one on the right. The wing on the left is pushed down by air pressing on the raised aileron, and the wing on the right is pushed up by air pressing below. Thus the aeroplane as a whole is tilted over to the left.

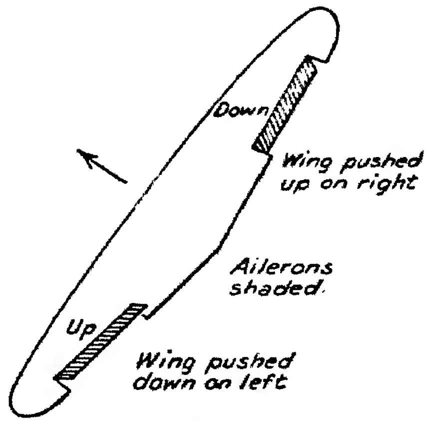


Fig 14.

When a pilot wants to turn to the right he must bank so that the wing on the left is raised. He moves the control so that the aileron on the left is lowered (so as to push that wing up), and the aileron on the right raised (so as to push that wing down).

Turning with the Elevator

We can actually turn a plane by using the elevator only. We go into a steep bank by using the control to the ailerons so that the wing on the outside of the turn is raised. Then we use the control to raise the elevator. The plane turns inward on the bank, and so makes the turn. If you have any difficulty in seeing why this happens, you can show how it is done by using a sheet of paper to represent the plane (Fig. 15). Hold the sheet flat in front of you; then move it forward at the same

time raising the leading edge. That represents an ordinary upward climb. Now hold the sheet of paper with the left-hand edge raised, so as to represent a steep bank. Once more move the sheet forward with the leading edge moving exactly as before. Continue the movement until a half circle is completed. The plane has turned, and is now on a backward course. We can take the plane out of the bank by reversing the ailerons, and can then continue the flight in the opposite direction.

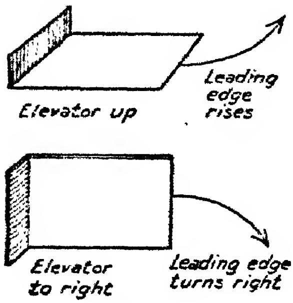


Fig. 15.

The pilot of an aeroplane has the controls to the elevator and ailerons on a single control stick. By pushing the control stick forward he can lower the elevator and so put the plane into a downward glide or dive. By pulling it back he can raise the elevator and so begin to climb. A movement of the control to the right raises the aileron on the right and lowers that on the left, thus putting the plane into a bank ready for a turn to the right. A movement of the control to the left puts the plane into a bank ready for a turn to the left. The rudder is controlled by the feet. Pressure by the right foot turns the rudder to the right, and so causes a turn to the right; pressure by the left foot causes a turn to the left.

Stalling

Everyone who has ever flown a kite knows that if the wind is not strong enough to support it the kite will come fluttering down, completely out of control. The strength of wind necessary to support a kite depends on the size and construction of the kite. One kite

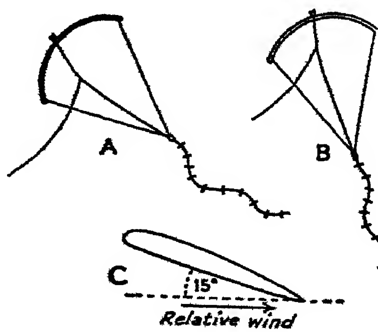


Fig. 16.

will fly quite well in a wind that will not support another at all.

There is another thing we may observe when flying a kite in a light wind. We have already seen how a strong wind may cause a kite to nose-dive if the tail is not heavy enough. Now see what happens when a light wind, which will just fly the kite, becomes lighter still. The plane of the kite becomes more and more upright (Fig. 16); and then suddenly the kite begins to flutter down. When that happens to an aircraft it is called stalling. The angle at which a kite begins to stall, or flutter down out of control, is more or less constant for any particular kite; but each kite has its own stalling angle.

Flying Speed

When we apply these ideas to aeroplanes we have to think of the speed of the plane against the air—that is, its "air speed." A plane runs along the ground, gathering speed as it goes, till it has attained its flying speed—that is, the lowest speed at which it can take the air. When the plane leaves the ground there is a rapid acceleration, because friction between the wheels and the ground is suddenly removed. The pilot can use this increase of speed to climb out of the way of obstacles round the aerodrome.

The plane must on no account be allowed to fall below its flying speed. If it does so (in attempting to climb too rapidly for example), it behaves like a kite in a wind which is too light to support it. It stalls. The controls cease to act, and the plane begins to fall like a dead thing.

Avoiding Stalls

Stalling is one of the most dangerous things that can happen to an aeroplane; it is the cause of many accidents. A pilot is warned that his plane is on the point of stalling by a slackening of the controls, and possibly by feeling that the plane is beginning to fall away from under him. As soon as he is aware of it he tries to get out of the stall before the plane is quite unmanageable. He may get into

a dive, or open out his engine, and so increase his speed. A stall close to the ground is most dangerous of all (unless of course the plane is so near the ground that a crash is not likely to do much harm). Even if the pilot can get his plane into a dive, he has to use the increased speed to climb at once, and this may bring on another stall. In such circumstances it needs a cool head and expert manipulation of the resources of the plane to stave off disaster.

Much thought has been given to the reasons for stalling. When an aeroplane is flying, the wings tilt upward at a small angle against the air (Fig. 17). The air flows smoothly over the front part of the wings, but there are small swirls, or vortices, near the trailing edge. If the speed of the aeroplane slackens, the wings strike the air at a greater angle, just as a kite becomes more nearly upright when the wind drops. The change happens automatically: the wings could not support the plane if they continued to present the smaller angle. At the same time the even flow of air over the wing is disturbed; the vortices creep nearer to the leading edge.

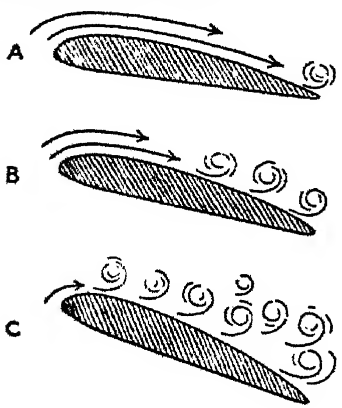


Fig. 17.

If the speed goes on decreasing, the wings become more and more inclined. Finally a maximum angle is reached: the *stalling angle*, just as happens with a kite in a light wind. At this angle the even flow of air across the wings is completely upset; the partial vacuum above the wings fills in, and two-thirds of the lifting power of the plane is lost. It is then that the plane begins to fall out of control.

When the speed of a plane slackens to the stalling speed, the wings take up the stalling angle. Every plane has its own stalling speed and stalling angle. These depend on the size and construction of the plane, just as they do in a kite.

Slotted Wings

It should be clear that anything that disturbs the even flow of air over the wings will help to bring on a stall. The stalling speed can be reduced and the stalling angle can be increased, to great advantage, by any means that will promote the even flow of air over the wings. That is the purpose of the famous Handley Page slotted wing. Along the leading edge of the wings small wings are attached (Fig. 18). When the plane is flying at high speed with the wings almost horizontal, the pressure of the air keeps these small wings flat against the main wing, as though they were part of it. When the wing tips up sufficiently the air presses under the small wings and forces them up. A strong stream of air is thus directed along the upper surface of the wing. This prevents the vortices creeping forward across the wing, and so postpones a stall.

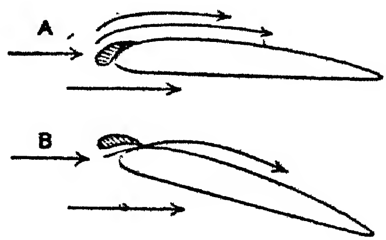


Fig. 18.

The Airscrew

When a kite or an aeroplane stalls, the plane or planes automatically make a greater angle with the wind than when flying normally; the planes slip into the position in which they can exert the greatest pressure on the air, and therefore give the maximum lift. The actual lift of any plane pressed against the air depends on its size, its speed, and the angle at which it meets the air.

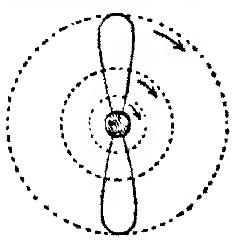


Fig. 19.

Now the speed at which any part of an airscrew rotates depends on its distance from the hub. Fig. 19 shows the distances through which parts of an airscrew rotate. The circumferences are in proportion to the radii. The greatest rotation is at the tip; half-

way along the blade the rotation is only half as great; at a quarter the distance along the blade it is only a quarter of what it is at the tip; and so on.

We want each part of the blade to have, as nearly as

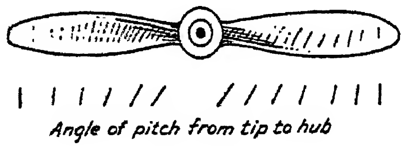


Fig. 20.

possible the same pressure on the air. We can achieve this by having the pitch of the airscrew (the angle at which it meets the air), least at the tips of the blades, and increasing toward the hub (Fig. 20).

Controllable Pitch

When a plane is travelling at low speed, say not more than 100 miles per hour, the pitch angle need not be great; in fact there is a disadvantage in having a high pitch angle. We know that a surface pushed through the air has less effect when the angle at which it meets the air is greater than the stalling angle. With an aeroplane wing there is less support. With an airscrew there is less pressure on the air, and less propelling effect.

If an airscrew has a fixed pitch, this pitch may be suited to taking-off conditions, when the speed is low, or to cruising conditions, or to high speed conditions. Whichever is chosen, the screw can only work at maximum efficiency at that speed. If we want the greatest efficiency from an airscrew at all speeds, we must be able to control the pitch so that it is very fine for small speeds, in taking off and in climbing, and coarse for high speeds.

The constant-speed airscrew operates automatically. It is intended to keep the engine running at a constant number of revolutions per minute, actually at the most economical rate. The engine has a governor which is coupled to a valve that admits oil under pressure to one side or other of a piston. When the oil presses on one

side of the piston, the pitch of the airscrew is increased; the blades are pivoted, and they are turned at a greater angle to the direction of flight. When the oil presses on the other side the pitch is decreased.

Suppose the engine begins to run above its constant speed. The governor swings out and opens the valve. The pitch is changed, and the engine is brought back to its constant speed. When the engine runs below its constant speed, a change occurs in the opposite direction in the governor, and thus in the pitch of the airscrew; this brings the engine back to normal.

The chief advantages of the constant-speed airscrew are that it prevents the engine running too rapidly (over-revving), and that it enables the engine to run rapidly when taking off, and so quickly to get up flying speed.

Black-out

Everyone has heard of the airman's black-out. In certain conditions an airman may become temporarily blind, and may even become unconscious for a short time. If he is flying at a great height in normal conditions, he quickly takes control again as soon as he recovers, and no great harm results. But if he is flying not far from the ground, or near an enemy plane, he may be in great danger.

We can travel at any speed, however great, and not be aware of it. People in the tropics are quite unaware, so far as feelings go, that they are rotating with the earth at 1000 miles per hour. It is only when there is a change of speed, either acceleration or retardation, that we become aware of it. In a motor car running smoothly we are barely conscious of movement, but we are quickly aware of any bumps or turns—indeed, of anything that produces change of movement or acceleration positive or negative.

We are aware of accelerations because they produce changes of weight. When we are at rest our weight is a downward pull. But we can feel the pull in any direction, even upward. The pull, or weight, is always opposite to the direction in which we are accelerated. In an aeroplane accelerating downward with great rapidity, the weight may even be felt as an upward pull.

"*g Men*"

A body falling freely has an acceleration of 32 feet per second in each second. Starting from rest, at the end of a second it has acquired a speed of 32 feet per second; at the end of two seconds the speed is 64 feet per second; at the end of three seconds it is 96 feet per second; and so on. This acceleration is usually called g. $\frac{1}{2}g$ is 16 feet per second per second; $2g$ is 64 feet per second per second, and so on.

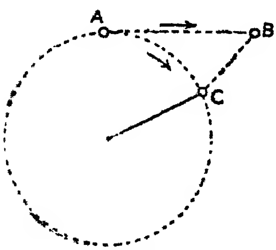


Fig. 21.

Airmen have been called "*g* men" (with a small "*g*") because they are subject to sudden increases of weight when their planes accelerate rapidly.

The most important accelerations occur when planes change direction by turning. Let us tie a weight to a string and swing it round in a circle. We feel the outward pull of the weight. The fact that the pull is outward suggests that there is an acceleration toward the centre, the point where the string is held. This is indeed the case. If the weight were free to move, it would fly off at a tangent, say from A (Fig. 21). In a second it might reach the point B. The string has constrained it, so that it moves along the circle; it has therefore been dragged towards the circle, and is continually being so dragged.

Measuring the Acceleration

There is a simple rule which gives the acceleration when a body moves in a circle. We turn the radius of the circle into feet, and the speed of the body round the circle into feet per second. Then we square the speed and divide by the radius. Those who like their rules in formulas can remember this as $\frac{v^2}{r}$

Suppose we have an aeroplane travelling at 240 miles per hour (Fig. 22). It begins to turn in part of a circle with radius 100 yards. We want to know the acceleration toward the centre of the circle.

$$240 \text{ m.p.h.} = 240 \times 5280 \text{ ft. per hour}$$
$$= \frac{240 \times 5280}{3600} \text{ ft. per sec.}$$
$$= 352 \text{ ft. per sec.}$$
$$100 \text{ yds.} = 300 \text{ feet}$$

The acceleration is:

$$\frac{352^2}{300} = 414 \text{ ft. per sec. per sec.}$$

To find how many times this is greater than g we divide by 32 feet per second per second.

$$\frac{414}{32} = \text{about } 13g.$$

That is a really terrific acceleration. Everything in the

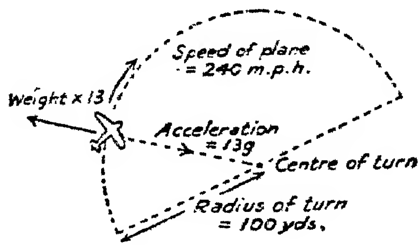


Fig. 22.

plane has its weight suddenly multiplied by 13, and this weight is felt as an outward drag, away from the centre of the circle.

This example shows why it is necessary not to attempt too sharp a turn, especially when travelling at high speed. If the turn has a radius of 200 yards, the acceleration is reduced to half, or to $6\frac{1}{2}g$. With a radius of 400 yards the acceleration is again halved; it becomes $3\frac{1}{4}g$. If the speed were half as great the acceleration would also be reduced to a quarter.

Effects of Accelerations

The sudden accelerations that occur during turns, with the great increases of weight that accompany them, are extremely important to airmen. The weight of the blood may suddenly become five or six times as great as the

normal weight; the heart is not powerful enough to pump such heavy blood through the arteries, and blood drains away from the eyes. That is the cause of the airman's black-out. Any acceleration greater than about 6*g*, if it is continued for longer than about 4 seconds, is apt to cause a black-out.

Aeroplanes have to be powerfully built to withstand the enormous stresses, due to great increases in weight, that are incurred during turns. There is a limit to what any aeroplane can stand, and airmen have to avoid turns so sharp that the increase in weight would wrench the plane to pieces.

4.—LEATHER "SUCKER" AND ANEROID

Can you answer these questions?

How does a leather sucker work?
What is a partial vacuum?
What pressure is represented by "an inch of mercury"?
How are jam-pot covers held down by air pressure?
What is the connection between the volume and pressure of a mass of gas?
How does a pop-gun work?
How does an air-gun work?
How is air pressure used to prevent doors banging?
How is air pressure used to prevent lift accidents?
What is the advantage of pneumatic tyres?
How do we calculate air pressure from the height of the barometer?
What is the advantage of using a glycerine barometer?
How does the aneroid work?
What is the altimeter?
How is the altimeter set?
When are compressed-air machines used?
How does a bicycle pump work?
What is a servo-motor?
How is a torpedo driven?
What is a pitot tube?
How does an air-speed indicator work?
How can the speed of the wind be measured?

The leather "sucker" is an old familiar toy, and a very fascinating one. We used to get an odd piece of leather from the shoemaker; we cut out a circle 3 or 4 inches across, made a small hole in the centre, pushed a string through, and knotted it below (Fig. 1). We always put the undressed side of the leather below. We soaked the leather in water for at least twenty-four hours, and it was then ready to be used as a sucker.

Most people know how a sucker is used. We put it on a flat stone, and press it down tightly with hand or foot, in order to squeeze out air from below it. Then we raise

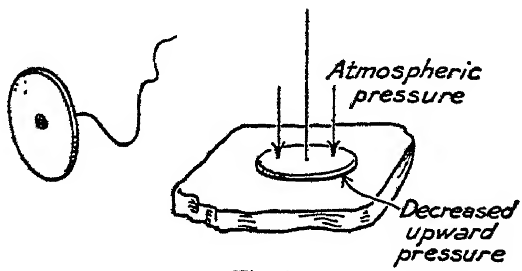


Fig. 1.

the sucker by means of the string, and if we have any kind of luck the stone is raised too. If we did not succeed in raising the stone the first time, we could always try again. Another thing we could do with the sucker was to press it against a wall, and then attempt to draw it away. There was a great satisfaction in feeling the resistance to our attempts.

It is possible to get even more spectacular results with a larger sucker. I remember using one, a foot or more across, to lift a heavy paving stone.

It is not difficult to see how a sucker works. When we merely place it on a flat surface there is air below it as well as above; the upward pressure of the air below is equal to the downward pressure of the air above, and nothing particular happens. When we put a foot on the sucker, and press firmly, we press out the air below it, or at any rate sufficient to make a fair difference between the

downward and upward pressures. The unbalanced downward pressure holds the sucker firmly to the stone; we use this pressure to lift the stone.

There is no doubt that it is air pressure that makes the sucker work. When we try to raise a good sucker from a flat surface we feel a strong resistance. If, however, we raise the sucker at the edge, so as to let in air below, then the sucker comes away with the utmost ease.

Paper Sucker

There is a kind of brown paper sucker that is interesting to use (Fig. 2). To make it, we want a large sheet of good tough brown paper. We can strengthen it at the middle by pasting squares or circles of paper above and below. We make a small hole in the middle, push a string through it, and tie the string to a small rod below (this is better than knotting the string). We spread the sheet of paper flat out on a table, and then we raise it slowly by means of the string. Nothing particular happens: the paper rises very much as we should expect it to. We now spread the paper out flat once more; we press it down smoothly and evenly so as to leave as little air below it as possible. Then we try to raise it by means of a sudden tug at the string. There is a surprising resistance, and the paper is sucked in towards the middle. It is possible to raise a sheet of thick cardboard, or even a square of three-ply wood by means of this sucker. The weight soon falls off, as air seeps in below and equalises the pressures above and below the sucker.

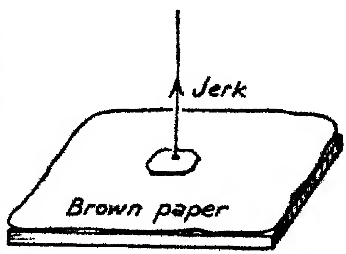


Fig. 2

When we raise the sucker slowly there is plenty of time for air to get in below it; the paper is not held down, because pressures above and below are equal. When we try to raise it by means of a sudden jerk there is no time for air to get in below, so we have the full air pressure above

the sucker, and a lesser upward pressure below it. We know that the downward pressure of the air (the usual atmospheric pressure) is about 15 pounds per square inch. The upward pressure below the sucker is not much less. Suppose it is a hundredth of a pound per square inch less; that is, it is 14.99 pounds per square inch. The extra downward pressure on the sucker is a hundredth of a pound per square inch. If the sucker is 16 inches square the total extra pressure downward is $16 \times 16 \times \frac{1}{100} =$ about $2\frac{1}{2}$ pounds. That is the weight that the sucker is capable of lifting for a short time.

A Partial Vacuum

We often express the difference in pressure above and below the sucker by saying that there is a partial vacuum below it. We often give the measure of this partial vacuum in "inches of mercury". The mercury barometer stands at about 30 inches; so 30 inches of mercury = about 15 pounds pressure per square inch. An inch of mercury represents a pressure of about $\frac{1}{2}$ pound per square inch. The partial vacuum does not last long; air enters all round the edges of the sucker, and before many seconds have passed the pressure below is once more equal to the pressure above. The sucker quickly loses its power of lifting a weight.

Breaking a Stick by Air Pressure

There is another way in which the effect of a partial vacuum under a large surface may be shown. We lay a thin flat stick with half its length over the edge of a table (Fig. 3). We lay a large sheet of paper on the table, so as to cover the stick with plenty of space all round. We spread the paper out flat and smooth it down evenly, so as to press out air from below it. We press the outer end

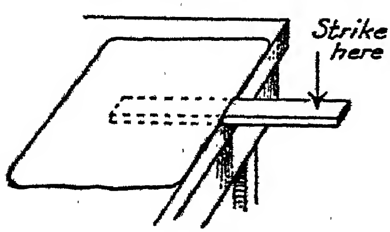


Fig. 3.

of the stick gently; the paper rises slowly, because air can readily get in below it, and there is nothing to hold it down. Now we replace the paper, smooth it down once more, and then strike the projecting stick with a hammer or a walking-stick. The sheet of paper is thus raised suddenly near its middle, a partial vacuum is formed below it, and the sheet is held down firmly by the greater ir pressure above it. Very often the stick is held down so rmly that the blow of the hammer breaks it in two.

Sealing Jam Jars

A partial vacuum can be used in many interesting ways. Metal jam-pot covers are sometimes held firmly in place y means of a partial vacuum below them. The cover s put on when the top part of the jar is filled with ot steam. When the jar cools, some of the steam ondenses, and so a partial vacuum is formed. The cover s held down firmly by the greater air pressure above. To elease the cover we slip the point of a knife under it, so hat air can get in below; the smallest opening is sufficient. The air pressures above and below the cover are equalised, nd the cover can then be lifted off.

Small rubber cups are sometimes used to hang objects n shop windows. A cup is placed with its rim flat on the window; it is pressed down at the middle, so as to squeeze ut air from below it, and so create a partial vacuum. It dheres firmly to the window because of the greater utside pressure. The smoothness of the glass window nables the rim of the cup to adhere closely, so that air annot seep in. These small rubber cups will sustain a onsiderable weight. The smallest puncture in one of hem will release it from the glass at once, because air will ush in, and the partial vacuum will be filled in.

Pressure and Volume—a Simple Rule

Some toys, and the inventions that they led to, are based on increased air pressure instead of a partial vacuum. When we want to increase the pressure of air we have to compress t in some way; that is, we have to press it into a smaller

space. There is a very easy rule for remembering by how much the pressure is increased: if we halve the volume we double the pressure (Fig. 4). If we take two cubic feet of air and squeeze it into a space of one cubic foot, we double its pressure; instead of having a pressure of 15 pounds per square inch, it now has a pressure of 30 pounds per square inch. If we were again to halve the volume, by squeezing it into $\frac{1}{2}$ cubic foot, we should again double the pressure, which would then be 60 pounds per square inch. If we were to squeeze the 2 cubic feet of air into a space of $\frac{1}{10}$ of a cubic foot, or $\frac{1}{20}$ of the original space, the pressure would be 20 times as great, or 300 pounds per square inch. Such great increases of pressure show why compressed air can be used to drive machines. Of course, the same great pressure must be used in compressing the air, so there must be some other source of power.

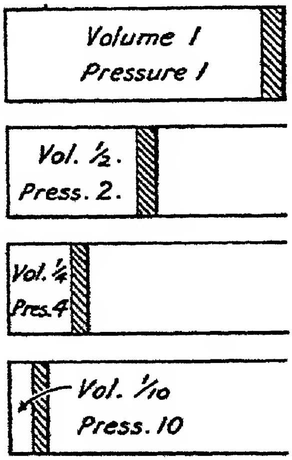


Fig. 4.

How the Pop-gun Works

The pop-gun is a simple toy that depends on a small increase in air pressure (Fig. 5). It has a barrel with a piston that will slide to and fro in it. The piston is drawn back, and the barrel is tightly corked. The piston is then pushed along the barrel. The space between piston and cork is decreased, but no air can escape; the air is compressed into a

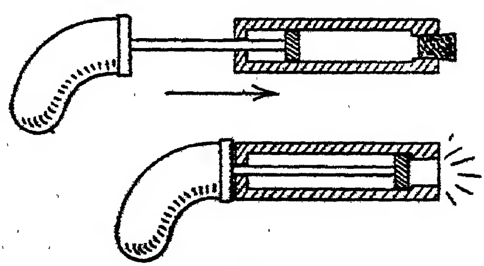


Fig. 5.

smaller space, and so it presses strongly on everything about it, including the cork. As the piston moves along the barrel the pressure increases, until at last it is great enough to drive out the cork; and as the cork is driven out, the compressed air escapes with the loud "pop" from which the gun gets its name.

Air-guns

Air-guns are a development of the pop-gun. Compressed air is used as the motive force for driving some sort of projectile. This may be a ball, or a small dart with a fluff of hairs to keep it moving point foremost, so as to stick to a target. We want some method of compressing the air which is to serve as a propellent.

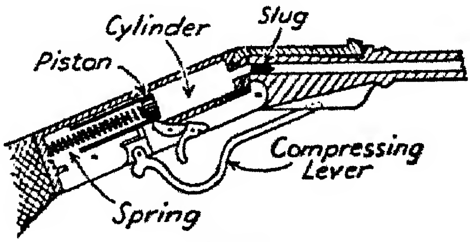


Fig. 6.

It is usual to have the barrel in two parts, hinged together, so that it can be "broken" at the middle (Fig. 6). A lever is attached to the front part of the barrel, near the hinge. As the front part is bent down, the lever is pressed back with considerable force. In one form of air-gun the lever is used to compress a spring inside the back half of the barrel. A dart or bullet is inserted in the front half of the barrel, at the break, and the barrel is closed. The trigger is pulled, and the spring is released. It compresses the air before it, until sufficient pressure is developed to drive out the projectile. In another form, the lever as it moves back compresses air into a compression-chamber in the stock of the gun. The pulling of the trigger opens a valve that admits the compressed air to the barrel to drive out the projectile. Several shots may be fired from one compression, but with decreasing force.

Air-guns can be shot with considerable accuracy at short ranges. The pressure of the compressed air is much less than that of the masses of hot compressed gases formed suddenly by an explosive charge, so that an air-gun is not effective at long ranges. Compressed air has, however, been used as a propellent in large guns, especially in America. The biggest of these guns had a barrel diameter of 15 inches, and fired a shell weighing nearly half a ton. The greatest range was about a mile and a half. The compressed air was enclosed in metal tubes; it had a pressure of about 60 atmospheres. In the Spanish-American war of 1898 the gunboat *Vesuvius* actually fired shells from her three air-guns at Santiago.

Air "Cushioning"

Sometimes the door of a small room opens outwards, and a peculiar effect may be observed. If the door is closed slowly there is nothing in particular to observe. But if the door is closed suddenly the mass of air in front of the door is pushed into the room. The air pressure inside the room is suddenly increased, and the air presses outwards on the door; this outward pressure is felt as a cushioning effect. In a large room the small amount of additional air forced in by the closing door would have very little effect, because it would be spread out over a considerable volume. The effect is greatest in a very small room.

The cushioning effect of compressed air is used as a means of preventing doors banging. A cylinder is fixed at the top of the door, with a piston sliding to and fro in it. The opening of the door presses the piston along the cylinder and air is drawn into the cylinder. The closing of the door compresses the air in the cylinder, and so cushions the movement. The compressed air escapes through a small opening, and this permits the door to close slowly. If we try to close the door too quickly there is a considerable resistance by the compressed air; this resistance ceases when the air escapes.

Preventing Lift Accidents

In high lifts there is a danger of serious accidents if the lift should fall out of control. The cushioning effect of compressed air can be used as a means of preventing such accidents. The well of the lift is strongly built in, so that air does not easily escape from it. A lift falling out of control compresses the air below it into a space which decreases in size as the lift falls. Thus the upward pressure of the air below the lift steadily increases as it falls, until it more than balances the weight of the lift. The lift is brought to rest gradually, and descends the last part of the shaft slowly, as the compressed air escapes round the sides.

Pneumatic Tyres

Probably the most important invention depending on the cushioning effort of compressed air is the pneumatic tyre. At the Dunlop works in Birmingham they still show a replica of John Boyd Dunlop's original model of a pneumatic tyre (Fig. 7). It is a wooden wheel with a cloth tube tacked round the rim. That was how he expressed his idea. What he wanted was a metal wheel with a rubber tube round it; and that was what he got. The bicycle pump compresses air into the tyres of the bicycle. The bumps and jars to which the wheel is subject as it moves over uneven roads are spread out by the compressed air, and so the bicycle moves smoothly. The pneumatic tyre sounded the death-knell of the old solid-tyred cycles—"bone-shakers" as they were called.

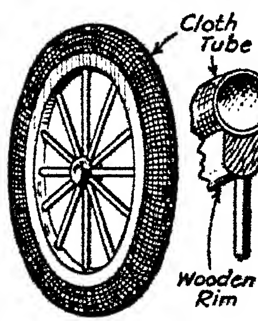


Fig. 7.

Calculating Air Pressure

We come back now to the old leather sucker, with its important lessons about air pressure. Out of those lessons came the aneroid barometer: the barometer that is "not

wet", for that is what the word means. The earliest barometers, and many that are still used, have a column of mercury that balances the downward pressure of the air. The column of mercury usually stands at a height of something like 30 inches. If we imagine the column to have a cross-section area of a square inch (Fig. 8), then a square inch at the base of the column supports a pressure due to the weight of 30 cubic inches of mercury; and of course any other area would have a proportional pressure on it. It is not a difficult problem to find the weight of this quantity of mercury. We know that a cubic foot (1728 cubic inches) of water weighs $62\frac{1}{2}$ pounds, and that mercury is 13·56 times as heavy as water. Here is the sum:

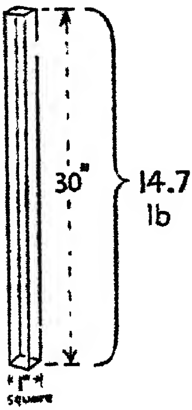


Fig. 8.

1728 cu. in. of water weighs $62{\cdot}5$ lb.

1 cu. in. of water weighs $\dfrac{62{\cdot}5}{1728}$ lb.

30 cu. in. of water weighs $\dfrac{62{\cdot}5 \times 30}{1728}$ lb.

30 cu. in. of mercury weighs $\dfrac{62{\cdot}5 \times 30 \times 13{\cdot}56}{1728}$ lb.

$= 14{\cdot}7$ lb.

The weight of the column of mercury is about 14·7 pounds on each square inch; that is a measure of the air pressure at sea-level: about 14·7 pounds per square inch, or just over a stone on each square inch of surface. On a square foot the pressure is 144 times as great, or 14·7 × 144 pounds = about 2117 pounds, or just under a ton. A pressure of 14·7 pounds per square inch is called an atmosphere.

The Glycerine Barometer

In passing it may be mentioned that glycerine is sometimes used in barometers. Glycerine is much lighter than

mercury, so it is necessary to have a much longer tube. The specific gravity of glycerine is 1·28 (a little more than $1\frac{1}{4}$ times as heavy as water), compared with 13·56 for mercury. Hence the length of the glycerine column is $\frac{13\cdot 56}{1\cdot 28}$ = about $10\frac{1}{2}$ times the length of the mercury column. The total length of the tube is about 27 feet, so that we want some kind of a cellar for the lower part of the tube if the upper part is to be at a level where it can be comfortably read. The advantage of the glycerine barometer is that it moves $10\frac{1}{2}$ inches for 1 inch on the mercury barometer, and so gives more exact readings.

How the Aneroid Works

The aneroid barometer contains a circular metal box from which air has been pumped out (Fig. 9). The back of this box is firm enough; the front is thin and has circular corrugations. The front of the box would be forced in by the outside air pressure, but for one thing: it is supported at the centre by a metal bar which is held up by a strong spring. When air pressure is high the front of the box is forced in; when air pressure is low the front is less forced in; it moves outward a little. Thus the in-and-out movements of the thin front of the box provide a means of measuring the air pressure.

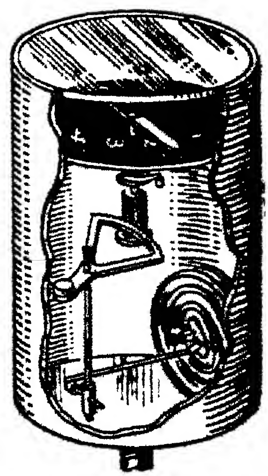


Fig. 9.

We now want means of exaggerating these movements of the box-front, and of communicating them to a pointer. The movements themselves are very small, so a fair amount of exaggeration is needed. A light lever is attached to the spring, and thus goes up and down with the spring; the outer end of course moves considerably more than the

inner end where the spring is. A smaller lever is attached to the chief lever; this lever moves a small chain which passes round a sprocket wheel and turns it. A pointer is attached to the sprocket wheel, and this again magnifies the movement; a small turn of the axle gives a much greater turn of the end of the pointer. This magnification multiplies the previous one, so that the total magnification is considerable. The system of levers and chain changes the up-and-down movement of the exhausted box to the circular movement of the pointer over a dial. The multiplication of the movement is 600 or 700 times, and sometimes more.

The aneroid is graduated by comparison with the mercury barometer. The position of the pointer is marked on the dial for two pressures as widely apart as possible. The dial can then be graduated between the marked points and on both sides of them.

Aneroid Inaccuracies

The aneroid barometer is very convenient for carrying about in places where the long glass tube of a mercury barometer would be just about impossible. It has, however, the disadvantage of being less accurate. The elasticity of the exhausted box may change, and so the instrument may give different readings. Levers, chain and spring may be slightly fouled, and this also would cause inaccuracy. Change of temperature is another cause of inaccuracy; when the temperature goes up, levers and other parts are slightly longer, and so the readings are changed. In older forms of the aneroid a spiral spring was attached to the chief lever which also expanded with increase of temperature; it was so arranged as to compensate for other expansions. In spite of recent improvements, an aneroid barometer is not reliable unless it is corrected from time to time by comparing it with a mercury barometer.

Aneroids on Mountains

The aneroid barometer was invented by an Italian physicist called Vidi. It was patented in England in 1844,

and introduced to the British Association in 1848. Its convenience for carrying about from place to place was soon realised. Whymper took aneroids with him when he climbed the higher Andes, as well as two very inconvenient but reliable mercury barometers. At comparatively low altitudes, and correspondingly high barometric readings, he found that the aneroids were reliable enough. It was only at high altitudes, and the correspondingly low pressures, that he found them unreliable. On one occasion when the mercury barometers showed a pressure of 14·1 inches, two of the aneroids showed 13·1 inches and 12·0 inches respectively. That was a discrepancy that showed them to be quite unreliable at low pressures.

The Air Pilot's Altimeter

The altimeter, or height-measurer, which is one of the most important instruments carried on aeroplanes, is nothing more than a simple development of the aneroid barometer. We know that as we rise higher, say in going up a mountain, or in climbing in an aeroplane, the air pressure decreases. The reason for the decrease in pressure is that there is less air above to press down. If the air had the same density throughout, the decrease in pressure would be proportional to the height. In the first thousand feet there is a fall of about an inch; this would be followed by a fall of another inch in the next thousand feet, and so on, till there was no pressure at all (and of course no air at all) above a height of 30,000 feet or so.

It is not quite so simple as all that. We know that the air is elastic. It can readily be compressed under pressure till its density is twice as great, ten times as great, a hundred times as great, or even more. Equally, if we reduce the pressure on a mass of air we reduce the density. If the pressure is reduced to half, for example, the density also is reduced to half. Now, as we climb upwards, on a mountain or in an aeroplane, we come to air that is thinner and thinner (or rarer and rarer). Near sea-level a rise of 1000 feet causes a fall of an inch in the barometer. Suppose we climb, like Whymper, to a height where the pressure is only about 15 inches of mercury. The pressure, and the

air density, are only a half of what they are at sea-level. A rise of another 1000 feet would place only half as much air below us as a rise of 1000 feet from sea-level. This rise of 1000 feet would cause a fall of only half an inch of mercury, or its equivalent on the aneroid. At still greater heights the fall in the barometer per 1000 feet would be even less. And the higher we go the less the fall per 1000 feet would be (Fig. 10).

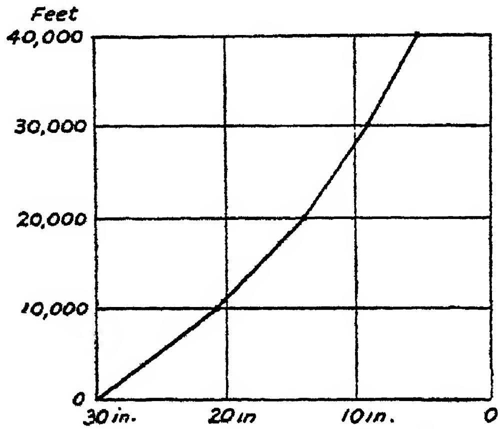


Fig. 10. Fall of air pressure with height.

We now come to the most interesting point of all. We know how the air pressure varies with height—say, 30 inches at sea-level, 29 inches at a height of 1000 feet, and then smaller and smaller falls for each additional increase in height of 1000 feet. Instead of marking the pressures on the dial of the aneroid, we can mark the height at which these pressures are encountered. And so we have the altimeter.

Improving the Altimeter

The older aneroids, as we have seen, were not too reliable, but many of their faults have been corrected in the altimeter. The temperature error has been reduced to less than a tenth of what it used to be by means of balancing springs and metal spirals.

The metal spirals are made of two metals securely clamped together. An increase in temperature causes one metal to expand more than the other. A greater expansion on the inside causes the spiral to open out; a greater contraction, with fall of temperature, causes it to close in. These movements are so arranged that they automatically make temperature adjustments.

The effect of expansion on one side of a compound strip may be shown, amusingly, by means of a dandelion stalk. We split the stalk down the middle into strips, and at once drop them into water. They coil up in the oddest ways, and always with the spongy inside surface of the stalks on the outside of the coil. The spongy surface absorbs water and swells out, thus causing the coil.

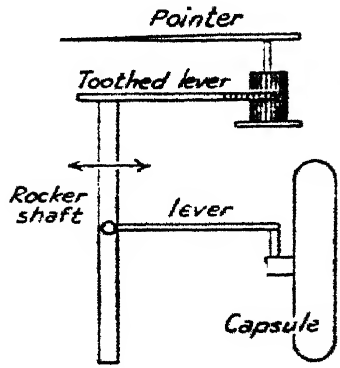


Fig. 11.

Another improvement is to use two or more exhausted boxes, or capsules, connected with one another so as to increase the amount of variation indicated. The instrument is made even more sensitive by the use of further levers and gear-wheels. As a result of these improvements, some of the new altimeters can be read so as to show differences of height of as little as five feet. Fig. 11 shows the arrangement inside an altimeter.

Setting the Altimeter

Air pressure is continually changing; at any particular station the barometer rises or falls from hour to hour. Now it is the difference in barometric height that shows the altitude. A station at sea-level may have a barometric height of 30 inches; 1000 feet up the pressure is 29 inches; the difference of an inch indicates an altitude of 1000 feet above sea-level. If the barometer falls half an inch it

stands at 29½ inches at the lower station, and at 28½ inches at the higher station; there is still a difference of an inch. Hence, the pilot who is reading the altimeter wants to know the difference between the ground reading and the reading at his own height. Before starting off on a flight he sets the altimeter to zero, and it then records heights above the point for which it was set.

During a long flight the barometer may rise or fall considerably, and this would introduce a large error into the readings. A fall of a quarter of an inch in the barometer would give readings 250 feet too high near sea-level, and there would be an even greater error at greater heights. With such an error vitiating the readings, it would be absurd to attempt to read the altimeter to the nearest five feet, and it might easily be dangerous.

The chief use of very sensitive altimeters is in a "blind" approach to an aerodrome, when the pilot has no view of surrounding objects to help him. The pilot wants to know his exact height above the aerodrome where he proposes to land. He asks for, and receives, the barometric height; he can then set his altimeter to this height as zero, and so he can read his height above the aerodrome with some exactness.

Compressed-Air Machines

We have not by any means come to the end of air-pressure inventions that were foreshadowed by toys. In the pop-gun and the air-gun we have compressed air used as the source of power, and it can be employed for other purposes. The more densely air is compressed the more strongly it presses on everything round it. It is quite possible to compress 100 cubic feet of air at atmospheric pressure into a space of 1 cubic foot. The volume is reduced to one-hundredth, so the force with which it presses outwards is multiplied by a hundred. We know that the pressure of the ordinary air is about 15 pounds per square inch; so the pressure of air compressed to one hundredth of its normal volume will be 1500 pounds per square inch, and that is nearly $\frac{7}{10}$ of a ton on each square inch. Pressures of that power can be used to drive large machines.

The Bicycle Pump

In order to compress air we must have some kind of an air pump. If we want a pressure of half a ton per square inch from compressed air, we have got to exert a pressure of half a ton per square inch in compressing the air.

For the small job of inflating a bicycle tyre, the usual bicycle pump is quite efficient; our hands and arms are capable of exerting the amount of pressure we want in the inflated tyre. The whole of this pressure is concentrated on the small area of the barrel of the pump, something like

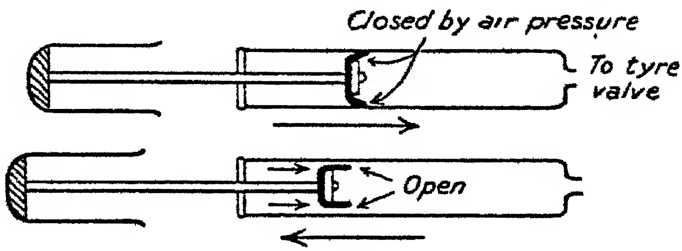


Fig. 12.

a square inch; that is why we can get a high pressure in the tyre.

The bicycle pump, like other compression pumps, has two valves both opening inwards, that is towards the tyre. The inner one is the tyre valve. At the end of the plunger is a leather cup turned downwards (Fig. 12). When the plunger is pushed down it compresses the air in the barrel. The compressed air pushes the rim of the leather cup tightly against the barrel, and so prevents the air escaping backwards. The point about this device is that the greater the compression, the greater is the safeguard against the air escaping. On the upstroke air readily passes round the rim of the leather cup into the lower part of the barrel.

What Bramah Did

The barrel valve is just about as simple and effective as such a valve can be. It seems obvious enough now; but it took the inventive genius of Bramah to think of it and

apply it. He used the same principle in the hydraulic press, which is usually called the Bramah press in his honour.

The hydraulic press had been known as a theoretical possibility. Just as we pump air into a tyre, so we can pump water into a space under a large ram. We should get the same force, per square inch, on the large area of the ram as we exert per square inch on the small area of the pump. Unfortunately there was so much leakage round the ram that the device was practically useless.

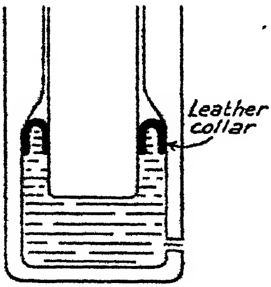


Fig. 13.

Bramah's contribution was the addition of a leather collar round the ram (Fig. 13). The pressure of the water forced one side of the collar tightly against the ram and the other side against the barrel in which the ram moved. The collar effectively checked leaking, and the theoretical possibility became the highly practical Bramah press.

The same idea is used to prevent leaking in many machines. Stuffing is used round pistons for this purpose; the stuffing is compressed by pressure and ensures a tight fit. Split rings open out under pressure just sufficiently to prevent leakage.

Compression Pumps

When we want highly compressed air, capable of driving heavy machines, we have to have compression pumps driven by engines capable of exerting the high pressures required. Powerful steam engines are often used. The pumps themselves act in very much the same way as the simple bicycle pump, though more elaborate plungers and valves are needed to withstand the high pressure. As in the bicycle pump, there are two valves, both opening inwards; one valve is in the plunger, and the other at the opening into the compression chamber (the chamber into which the air is compressed). The highly compressed air is often used to drive machines as quickly as it is com-

pressed, more air being constantly pumped into the compression chamber to keep up the supply.

Compressed Air in Coal-Mines

I remember creeping along on hands and knees in a coal-mine, in a passage where there was just room to get through. It was very warm down there, as it usually is in a deep coal-mine. Halfway along the passage a machine was working; it was being used to undercut a seam of coal, so as to make it easier to hew. My first thought was, "How terribly hot and stuffy it will be near that machine!" But when I reached it the air was delightfully cool and fresh. And then I remembered a great compression pump I had seen working up above the mine, with its plunger moving steadily to and fro. The air compressed by the pump passed down tubes to the mine and there it was used to drive machines like the one I had seen, as well as other machinery. As the compressed air was used up in driving the machine, it expanded and cooled, and so it helped to cool and freshen some of the galleries of the mine.

Compressed air is used in mines because steam engines are impossible. Burning coal would use up the air, and make it unbreathable, and would, of course, introduce the danger of an almost inevitable explosion. Compressed air can be used in the same way as steam to drive a piston to and fro in a cylinder. The actual source of power is the burning coal in the steam engine up above. The compressed air transfers the power to the engines down in the mine, in a form that is not dangerous. That is one very important use of compressed-air engines.

Servo-Motors

Compressed air is a convenient form of power for operating small auxiliary motors called *servo-motors*. On aeroplanes it drives the servo-motors connected with the automatic pilot. It is also used to rotate gyroscopes. The Whitehead torpedo is run by means of compressed air (Fig. 14); the front of the torpedo contains explosives and mechanism for firing them; the middle part is a flask

for holding compressed air; at the rear are the engine room, propellers, and the steering gear.

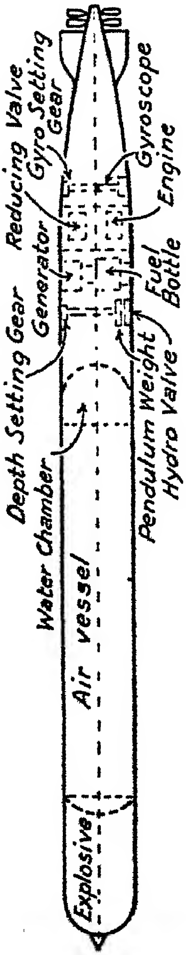


Fig. 14.

Sometimes we want to have a lot of small machines all working at once. We could provide each of the machines with its own engine, but compressed air provides a simpler and more economical method. A single large engine is used to work a compression pump. The compressed air is distributed through pipes to the various small machines, and is used to drive them. The mechanical drills, used to break up pavements are a familiar example of the use of compressed air to drive a number of small machines. Riveting machines are another example.

Air-speed Indicators

"Air speed " is the speed with which an aeroplane moves through the air. Unless the air is dead calm, air speed is different from ground speed, or the speed at which the plane moves over the ground. If a plane is heading into the wind, the ground speed is less than the air speed. If there is a following wind, the ground speed is greater than the air speed.

It is very important to a pilot to know his air speed with some exactness, especially when he is flying near the stalling speed or is preparing to land. The instrument for measuring air speed is called an *air-speed indicator*.

A French engineer of the eighteenth century devised a simple instrument for measuring the speed of flowing water; this instrument is called a pitot tube after the inventor. It is an L-shaped tube which is held upright in

the current, with the short horizontal arm facing up-stream (Fig. 15). The flowing water rises in the vertical arm, and the height to which it rises is a measure of the speed of the stream.

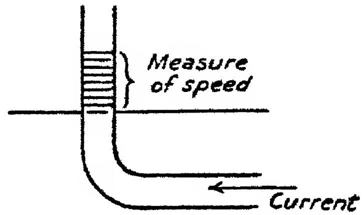


Fig. 15.

A pitot tube is used in the air-speed indicator (Fig. 16). The open end faces the direction in which the plane is moving, and above it is another tube which is intended to give the pressure of the air when not moving (the static pressure); the horizontal arm has small holes which admit air, but not the air current. The difference between the two pressures, the dynamic pressure in the pitot tube and the static pressure, gives a measure of the air speed.

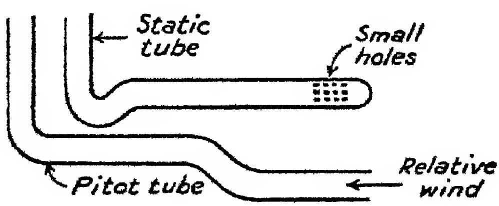


Fig. 16.

In one kind of air-speed indicator there is a silk diaphragm stretched across the middle of a box (Fig. 17). The pitot tube is connected with the space at the back of the diaphragm, and the static tube with the space in front. The middle of the diaphragm is pushed out more or less, according as the pressure in the pitot tube exceeds that in the static tube by greater or less amounts—that is, according as the air speed is greater or less.

A rod is attached to the middle of the diaphragm. The outer end of this rod presses on a lever, and so exaggerates and communicates changes in the position of the diaphragm to a pointer. The pointer turns on a dial marked in miles per hour or in knots.

There is an even simpler form of air-speed indicator

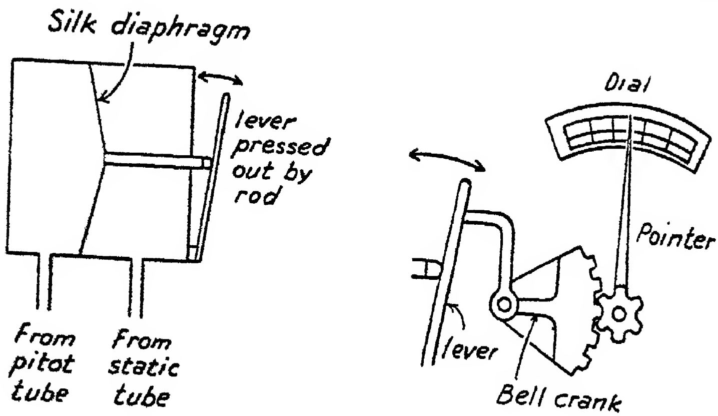


Fig. 17.

(Fig. 18). It consists of a flat sheet of metal facing the wind; behind this disk is a spring. Wind pressure on the disk compresses the spring; a rod attached to the disk is forced in, and a pointer is moved on the appropriate dial.

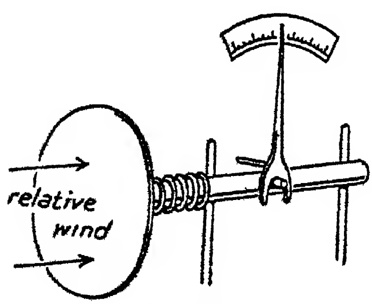


Fig. 18.

With a little adjustment any of the air-speed indicators can be used to measure the speed of the wind. In the diaphragm type there would have to be a small vane, similar to those used in windmills, to keep the pitot tube head on to the wind; indeed, some such mechanism is necessary in any adjustment of air-speed indicators to measure the speed of the wind.

5.—BITS OF GLASS, RAINBOWS, AND STARS

Can you answer these questions?

Which colours make white light?
How is light bent by a prism?
Which colours are bent most, and which least?
How do we know that it is the prismatic shape that causes the spectrum?
Why can we never reach the end of a rainbow?
What is the height of a rainbow?
What is internal reflection?
How can you make a rainbow?
How is a primary bow formed?
How is a secondary bow formed?
When are moon bows sometimes seen?
What is the spectroscope?
What is a diffraction grating?
How was helium first discovered?
What is an absorption spectrum?
What do Fraunhofer lines tell?
How are stars classified by spectrum analysis?
What kind of a star is the sun?
What does spectrum analysis tell about the planets?
In which planets is there a possibility of life?

LITTLE triangular bits of glass, of the shape that we call a triangular prism, used to be more common than they are now (Fig. 1). And that is a pity. We used to put one of these little prisms in front of the eye, and look at the world through it. We saw the world by means of the scientific magic that resides in a transparent prism; we saw it fringed with colours: red and yellow and blue, and if we looked carefully, green. It was always a puzzle where those colours came from; it was a puzzle that appealed to the mind of Sir Isaac Newton, and of other scientists who came after him.

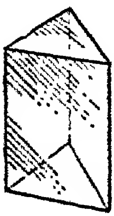


Fig. 1.

I say it is a pity those bits of glass, those little transparent prisms, are less common than they were, because we can use them to understand one of the most beautiful of natural phenomena, the rainbow. I have heard people say, "Why attempt to explain so beautiful a thing as a rainbow? Why not just admire it?" The answer is that we have questing minds that seek explanation, that ask "Why?" The trained eye can perceive many beautiful phenomena in the skies that are invisible to the uninstructed, just as the trained ear of a musician hears far more than the uninstructed ear of a savage.

Even though triangular glass prisms are less common than they were, one can always get good ones from the makers of scientific instruments. Such a prism is one of the best scientific toys in which one could invest a few shillings.

In a Dark Room

That house is very fortunate which has a room facing south that can be easily darkened. It need not be a big room; indeed, a small room is preferable. One of the best ways of darkening it is to cover the window with dark brown paper; when the window is completely covered, the room should be quite dark.

We want to admit a small beam of light, so we cut a hole,

two inches square, in one of the sheets of brown paper. On a sunny day that will admit all the light we need.

Very often we want a much smaller beam of light; we can always reduce the size of the hole by fixing a card over it. We very carefully cut a narrow slit in a postcard or other sheet of thin cardboard. The slit should be cut with a sharp penknife, so that the edges are clean. We want the slit to be as narrow as possible, so that it will admit a very narrow beam of light.

It is useful to have a small screen on which to throw the beam of light. A sheet of white paper may be pinned up, but it is better to have it mounted on a light wooden frame. Damp the paper before pasting it on the frame, and when it dries it will contract slightly, and smooth out. A small bracket at the back will keep the frame upright.

We also want a small mirror, so that we can change the direction of the beam of light, and throw it on to any particular spot. When the sun is high in the sky the light slants down at an uncomfortable angle. We put the mirror on a table near the window, and place it so that the beam falls on it. We turn the mirror, and prop it up so that the beam falls in any direction we want, on the white paper screen for example.

Splitting up White Light

Now let us see what we can do with this simple apparatus (Fig. 2). We turn the narrow slit of light so that it falls near the middle of the screen. We now place a triangular prism of glass in the beam of light, and we may have to turn it a little to get the best effect. An extraordinary thing happens, so extraordinary that we should be amazed at seeing it for the first time. The narrow beam of white light is shifted over to one side, and the white light is broken up into a band of colours. These colours are: red, orange, yellow, green, blue, indigo, violet. Most people can readily distinguish the first five of these colours, but many can detect no difference between indigo and violet.

That is a repetition of one of Sir Isaac Newton's most

famous experiments, the experiment that convinced him that white light is composed of that extraordinary range

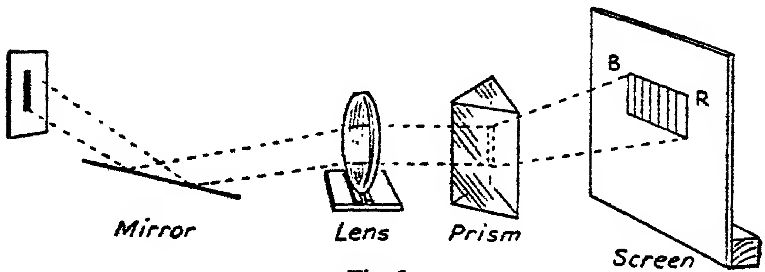


Fig. 2.

of colours. The prism he used is now in the British Museum.

The Use of a Lens

In order to get a really satisfactory result we want a small lens to concentrate the narrow beam of light on the prism. The lens can be mounted so that it will stand upright. We use a small wooden base, three or four inches square, and pin two strips of wood across it, with just sufficient space between them for the edge of the lens to be squeezed in. And that is all.

We place the lens between the window slit and the prism and move it slowly nearer to the prism till the band of colours is as sharp and clear as possible. The distance depends on the particular lens we are using; it will probably be about six inches.

How Light is Bent by a Prism

There is something else we should have noticed. Besides being broken up into the band of colours, the small beam of white light is also shifted over to one side. It is interesting to follow the course of the beam of light, and to see exactly how it is bent (Fig. 3). To begin with,

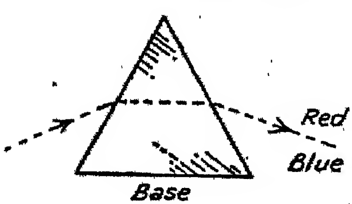


Fig. 3.

we draw a line round the base of the glass prism (we can place the prism on a sheet of paper). We look for the direction of the beam of light before it enters the prism, and we draw along that line. We draw a similar line along the beam that leaves the prism, before it has widened out much. It may be necessary to adjust the mirror a little, so that we can have the beam of light just grazing the sheet of paper on which the prism stands; that will be a great help in drawing along the beam.

It turns out that the beam of light is bent twice towards the base of the triangle, once where it enters the glass, and again where it leaves it. We can also see that the blue colours are bent more than the red; that is indeed why the colours are spread out into a band.

Now let us turn the prism very slowly, taking care to keep it in the narrow beam of light. The band of colours moves on the screen, and it may disappear altogether. We turn the prism so that the beam of light is turned as little as possible from its original position (this is the position of *minimum deviation*). When the prism is in this position the colours are brightest and clearest.

A Water Prism

Instead of a glass prism we can use a prism of water, or any other transparent liquid. Of course we need a container of glass, and here is a way of making one (Fig. 4). We want three small slips of glass. Cleaned lantern slides will do; or a builder would probably cut you strips of glass an inch wide and three or four inches long. We can use a small piece of wood as a base for the prism; we draw on the base an equilateral triangle with sides equal in length to the width of the strips of glass. Along two sides of the triangle we pin narrow strips of wood. Then we hold the strips of glass upright along the sides of the triangle, and we place a strip of wood so as to hold the third glass in position; this strip also is pinned down.

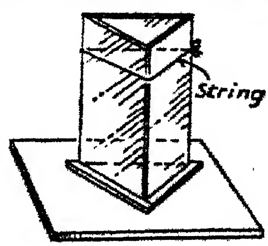


Fig. 4.

The strips of glass are tied firmly with thin string; it is advisable to tie them at both top and bottom. We now press a layer of putty on to the wooden base. We can press it down with the end of a stick, and we have to see that no gaps are left through which water can leak. We may also force a little putty into the angles where the glasses join.

We fill the little vessel with water, and so we obtain a triangular prism of water. We put the prism in the path of the beam of light, and again we see the beam spread out into a band of rainbow colours. We could use alcohol or glycerine instead of water and still find the band of colours. It is evident that it is the *shape* of the transparent material that causes white light to disperse into colours, and not the particular material we happen to be using. We need a transparent material, and a shape that has some resemblance to the triangular prism. An oblong (rectangular) prism would not do, for example, as we can readily see by looking through the water of an aquarium. Some transparent materials are better than others, because they spread out the rays more; and we should have to avoid using a liquid that would dissolve the putty.

A Rainbow in the Sky

The most spectacular example of the rainbow colours is seen of course in the rainbow itself. I remember one rainbow which I saw in ideal conditions; I give the story because it illustrates these conditions. We were walking back one evening across the fields through the rain to Croxley Green. It was nearly sunset, and I said, "If the sun were to break through now we should have the rainbow of a lifetime." Just as we reached the Green the sun did break through, and shone with glittering brilliance from the horizon. In front of us, with our backs to the sun, was a truly magnificent rainbow: a complete semicircle of brilliant colours reaching high into the sky, and with a brilliant secondary bow above it.

A rainbow is so familiar a sight, and attracts so much attention, that it is surprising that most people know so

little about it. Anyone can readily observe the most elementary facts about rainbows. In order to see a rainbow we have to turn our backs to the sun. Our shadows then point straight out to the middle of the bow. This suggests an odd fact about rainbows. Each observer sees a bow forming an arc of a circle about his own shadow, and so no two people see exactly the same rainbow.

Sometimes we can tell the distance of a rainbow because we can see it in front of a dark background, perhaps the edge of a wood. We may be able to see where it reaches the ground, but if we hurry over to that spot, we find that it is not there at all. It has moved on; it still forms an arc about our shadow, and it is as far off as ever.

If it is impossible to reach the spot where the rainbow ends, it is equally impossible to see a rainbow from the back, that is from the side away from the sun. To see a rainbow we have to turn our backs to the sun.

Height of a Rainbow

The height of a rainbow in the sky depends on the height of the sun above the horizon. If the sun is just on the horizon, when rain is falling, we may see a rainbow forming a great semicircle. On the side of a mountain it is possible, looking down the mountain slope, to see more than a semicircle. Rainbows have even been seen, from aeroplanes, that formed complete circles. The higher the sun is above the horizon the lower and shorter is the rainbow arc; so the best times to see rainbows are in the morning and evening. At midday, especially in summer, the sun is too high in the sky to form rainbows.

Internal Reflection

Before going on to consider how rainbows are formed, there is another simple experiment that we should try; it is just about the simplest of all experiments. We put a small stick in a tumbler of water, and holding the tumbler above the level of the eyes, we look up through the water from below. If we look straight up through the bottom of the tumbler we can see through the surface of the water,

and we can see the part of the stick above the surface. Now we hold the tumbler a little to one side, and we again look up at the under surface of the water (Fig. 5). We can no longer see through it. Instead, we see the under surface as a perfect mirror, with the lower part of the stick reflected in it. This kind of reflection is called *internal reflection*, because the reflection is from the inner surface of the liquid. One can often see examples of it when looking at the inner surfaces of liquids. When we look straight through an aquarium, for example, we can see through to the other side. But if we look sideways we can see reflections of things in the aquarium.

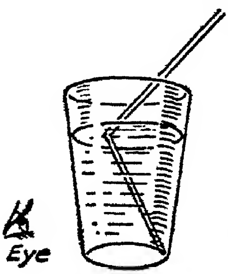


Fig. 5.

Making Rainbows

It is possible to produce small rainbows in various ways. On a sunny day fill a garden syringe with water, turn your back on the sun, and spray the water in the air in front of you. Small rainbows may be seen in the spray. We can even see two overlapping rainbows, one with each eye; close one eye and one rainbow only is seen.

By varying the pressure on the plunger we can vary the size of the drops in the spray; the harder the pressure the smaller the drops. Thus we can produce rainbows of different kinds, that is, with varying amounts of red and blue. In these small rainbows the red is on the outside, and the blue on the inside, just as in the large rainbows produced by the sun shining on a shower of rain.

It is possible to have a rainbow, or at any rate the rainbow colours, from a single drop of water. Sometimes it happens that rain falls in the night, and that the sun comes up bright and clear. That is the best time to see what the raindrops do.

We go out in the early morning, after a shower of rain. The grass is spangled with raindrops. The sun is still low in the sky; it shines on the raindrops, and we see them glitter with brilliant white light. We choose one drop to

look at. We move the eyes to right and left. Suddenly we get a brilliant flash of blue from the drop. We move the eyes slowly from side to side, and we see the whole range of rainbow colours. Perhaps the most startling are the red and yellow, seen together.

What a Raindrop Does

The raindrop has caught the magic of the glass prism. The magic has been analysed, and we have learnt from the analysis something about how rainbows are formed. Look at Fig. 6. AB is a ray of light falling on a drop of rain, horizontally or nearly horizontally. It is refracted, or bent inwards, just as a ray of light is refracted when it passes into a glass prism. It reaches the back of the drop at C. There it is reflected at the inner surface of the raindrop, just as we saw a small stick reflected at the inner surface of water in a tumbler. The ray emerges again at D, and as it does so it is once again bent, or refracted; as the ray of light emerges at the front of the drop it is bent down towards the eyes of an observer below.

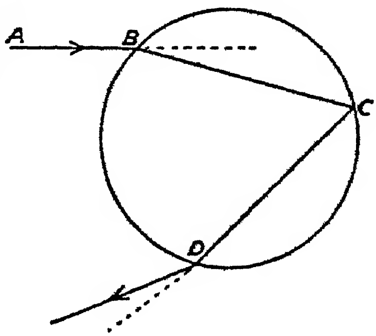


Fig. 6.

In passing through the drop of water the ray of white light is broken up into the rainbow colours. The final bend is an upward one, as may be seen from the diagram. If we have a drop of water in the right position, it will bend the red rays upwards just sufficiently to reach the eyes of an observer. The blue rays are bent upwards more sharply; they pass over the head of the observer, and he does not see them.

Fig. 7 shows three raindrops, A, B and C, sending red light to the eyes of an observer at O. Each drop is on the line OC. A drop in any other direction, say at D, would

end red light to an observer in some other position, but iot to the observer at O. All the drops that send red ight to O are in the direction OC, and at an angular listance POC from the ground. If we point an arm to ihe red of a rainbow we are pointing it in the direction OC.

The diagram need not be held upright. It applies equally well if we turn it in any direction about OP. As

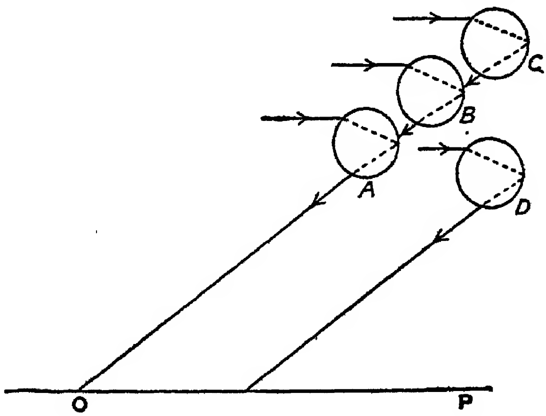


Fig. 7.

the diagram is turned, the line OC traces out the surface of a cone. Any raindrop on this cone would send red light to an observer at O.

Lower down in the rain-shower there are drops which turn the blue rays upwards just enough to reach the eyes of an observer. These drops do not turn the red rays up sufficiently and they pass below the eyes of the observer. The other rays, between red and blue, are similarly bent up by other cones of drops at different angles from the central line, and so we have the rainbow with its concentric arcs of different colours.

A rainbow is not quite so simple as that. The colours overlap, so that we get mixtures, and there is often some pink and green inside the bow. The purest and clearest colour is usually the red.

Measuring the Height of a Rainbow

We call the arcs " concentric," because they all have the same centre. We want to know where that centre is, and we begin by measuring the angular height of the rainbow. Here is an easy way of doing so. It is best done in the open when there is little or no rain.

We fix a thin nail or pin near the middle of one side of a drawing board (Fig. 8). We hold the board upright on a table with this side towards us. We turn the board till the shadow of the nail falls along the board; we draw along the shadow, and so obtain a line that points backwards to the sun. We look up past the nail to the top of the rain-

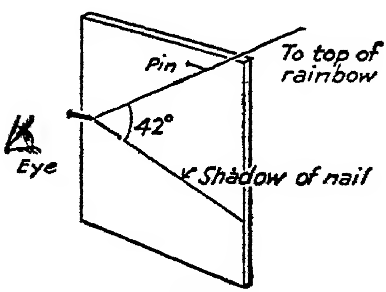


Fig. 8.

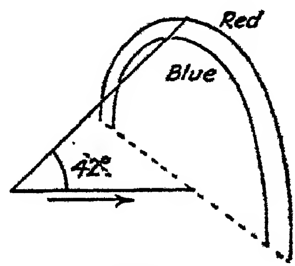


Fig. 9.

bow, and we fix a pin in the board in line with the nail and the top of the bow. We lay the board out flat, and draw a line joining the nail and the pin. We use a protractor to measure the angle between the two lines. This angle turns out to be 42°, and that is the angular height of the red edge of the rainbow above a line joining the sun to the centre of the rainbow. The centre is of course on the line along the shadow of the nail. It is usually below ground level. Only when the sun is just setting does the shadow run out horizontally. The red circle of the rainbow then rises to its maximum height of 42° (Fig. 9).

The angular height of the blue edge of the rainbow can be measured in the same way: it is 40°. Thus the angular width of the rainbow is 2°. Both sun and moon have the same angular width; this is almost exactly half a degree,

so that a rainbow has four times the width of sun or moon.

We have seen that the shadow of the nail points to the centre of the rainbow. The higher the sun is in the sky the more steeply does the shadow point downward. If the sun is 42° above the horizon the centre of the rainbow is

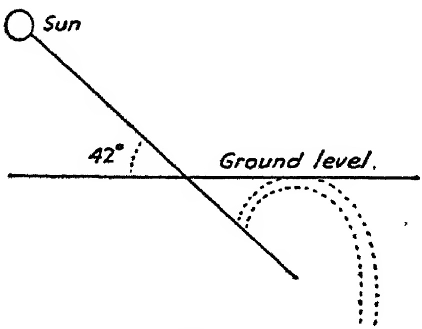


Fig. 10.

42° below the ground level. The top of a possible rainbow would be at ground level, so that no rainbow is visible (Fig. 10). That is why, as we have seen, rainbows are best seen in the morning and evening, and never at mid-day.

Circular Rainbows

When an aeroplane is high above the earth, the whole cone of rays may reach the eyes of observers in the plane

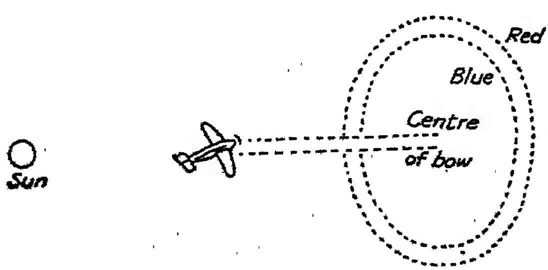


Fig. 11.

(Fig. 11). Shadows in the plane point to the centre of the rainbow. The whole angular width of the bow is 84°, not

far short of a right angle. Such a bow is most likely to be seen when the sun is very low in the sky.

Secondary Bows

Very often we see a secondary bow outside the first, or primary bow; indeed part of the secondary bow can nearly always be seen outside a primary bow.

The secondary bow is not so bright as the primary bow, and the colours are reversed, so that we have the red of the inner bow facing the red of the outer bow. The

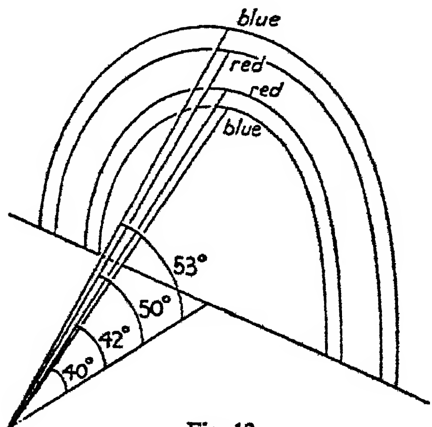


Fig. 12.

angular height of the secondary bow is 50° for the red and 53° for the blue, so that the angular width of the secondary bow is 3° as compared with 2° of the primary bow. This difference in width between the two bows may be readily observed (Fig. 12.)

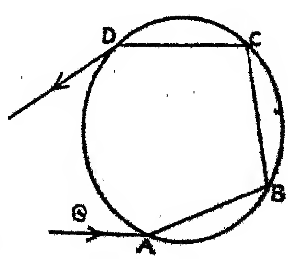


Fig. 13.

The secondary bow is explained by a double reflection inside the raindrops. It seems rather a lot to happen inside a small raindrop, but apparently it does happen. In Fig. 13 a level ray of sunlight is seen

entering a drop of rain at A; the ray must be in this position to allow the two reflections. The ray is refracted where it enters the drop; it is reflected twice, at B and C, from the inside surface of the drop, and then it emerges at D. It is refracted again at D, and the final bend is downwards. That is why the blue rays, which are bent most, reach the eyes from higher up than the red rays, which are bent least.

There are usually parts of "supernumerary bows"; these are bows, often pink and green, which are found inside or outside the chief bows.

A Little Exercise in Geometry

It is a pleasant little exercise in geometry to draw the path of a ray of light through a raindrop; and not too difficult, if we take it a bit at a time.

(i) We draw a circle two inches in radius to represent an enlarged raindrop (Fig. 14). We draw a horizontal ray of light, AB, entering the drop near the bottom. It must be near the bottom in order to get two reflections.

(ii) We want to find how this ray is refracted. We join B to the centre O, and continue OB outwards. At a convenient distance out from B, we draw AC at right angles to OB; we measure AC. On the other side of OB we draw a line parallel to OB and at a distance from it equal to $\frac{3}{4}$ of AC. With B as centre, and AB as radius, we draw an arc cutting the parallel line in D. We join BD and continue the line, if necessary, to meet the circle in E. BE is the refracted ray. (For those who wish to know why: $\frac{\sin ABC}{\sin KBD}$, the sine of the angle of incidence over the sine of the angle of refraction, must equal $\frac{4}{3}$ for air and water. $\sin ABC = \frac{AC}{AB}$, and $\sin KBD = \frac{DK}{BD} = \frac{DK}{AB}$. Hence

$$\frac{\sin ABC}{\sin KBD} = \frac{AC}{AB} \div \frac{DK}{AB} = \frac{AC}{AB} \times \frac{AB}{DK} = \frac{AC}{DK} = \frac{AC}{\frac{3}{4}AC} = \frac{4}{3}.)$$

(iii) It is quite easy to draw the reflected ray at E. We

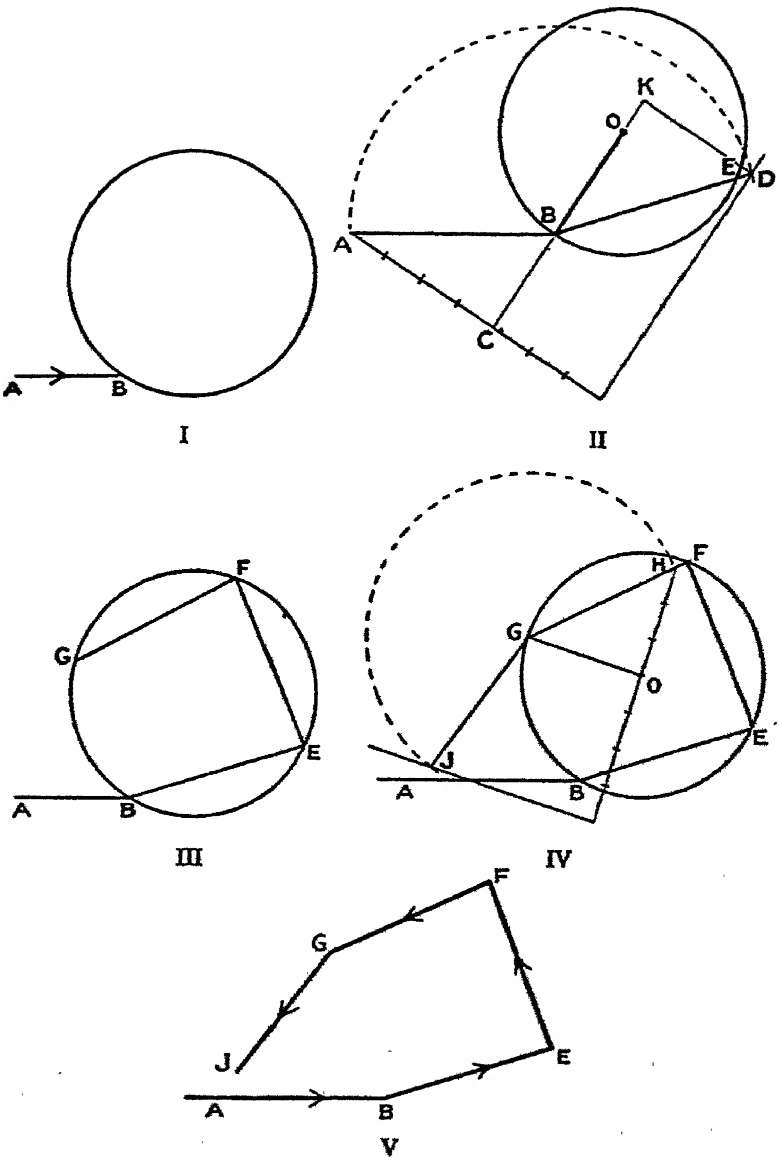


Fig. 14.

put one compass point at E, stretch out the compasses to B, and mark off this distance on the circle, at F. In the same way we get the second reflected ray, at G, by making FG = FE.

(iv) We now want the refracted ray at G. We have only to reverse the process of ii. We join OG. We draw OH at right angles to OG, and measure OH. On the other side of OG we draw a line parallel to OG, and at a distance from it equal to $\frac{4}{3}$ times OH. With G as centre and GH as radius, we draw an arc cutting the parallel line at J. We join GJ; this is the direction of the emergent ray. (The spreading out of the ray by refraction into the less refracted red, and the more refracted blue, has not been attempted, as it would confuse the diagram.)

(v) Now rub out the construction lines, and leave only A, B, E, F, G, J and the lines joining them. These lines give the directions of the ray of light.

To represent the refraction and reflection which produce the primary bow, we start with a ray near the top of the drop, but nearer the centre than the rays which produce the secondary bow. The geometry is the same, except that there is one reflection only.

Moon Bows

Rainbows are sometimes caused by the moon shining on falling rain. They are not nearly so bright as those caused by the sun, and they are only observed when the full moon is low in the sky. When there is a possibility of a moon rainbow we have to turn our backs to the moon in order to see it, just as we turn our backs to the sun to see a sun rainbow.

In the early morning dewdrops may be seen lit up with rainbow colours, and even a whole *dew-bow* may be seen spread out on the grass.

The Spectroscope

The little toy that has been used to explain the rainbow has been developed into one of the most extraordinary scientific instruments. It is the one that enables us to question the stars, and to read the answers they give.

The range of rainbow colours is called the *spectrum*, and the instrument for examining the spectrum is called a *spectroscope*. This instrument consists of a glass prism with three telescopes pointing towards it (Fig. 15). Telescope A is used for focusing light on the prism, just as we have already used a lens for this purpose. A small spectrum is formed. Telescope B is used for enlarging the spectrum, so that we can examine it in detail. Telescope C is something new. It is used to project the image of a scale on the prism, so that we can measure the positions of different parts of the spectrum.

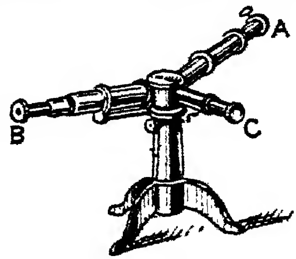


Fig. 15.

Colours and Wave-lengths

Heated or burning things give out light of different colours. A glowing coal fire gives out yellow and red light; if we throw a little salt on it we get a blue colour. We have all seen the brightly coloured flames of fireworks. Most of the colours are due to the presence of various metals in the blazing compositions. A blue light is given by burning sulphur, and also by a salt of antimony; for a green flame we can use nitrate of barium, and for a red flame nitrate of strontium.

The difference between one kind of coloured light and another is the difference between the wave-lengths of the light. The wave-lengths of red and yellow are the longest, and those of blue shortest. The long red rays are more penetrating than the short blue rays, which are more easily turned aside. The infra-red rays, which are longer even than red rays, are more penetrating still; a photograph taken with infra-red rays reveals things that are invisible to the eyes, because infra-red rays do not affect the eyes. The short blue rays are more easily refracted than the longer red rays, and so they are more bent when passing through a prism.

We have seen how white sunlight can be analysed into a

whole range of different colours; that is to say it contains light-waves of a great many different wave-lengths. Analysis by a prism arranges them in order from short (blue rays) to long (red rays).

Examining Spectra

When we want to examine the light given out by a flaming or glowing body we place it near the end of telescope A in the spectroscope (Fig. 15); this telescope focuses light on the prism, which analyses it into its various wave-lengths. Suppose we examine the light given out by the glowing filament of an electric lamp. When the filament glows dully it gives out a reddish light, and the spectrum is almost entirely red. When a stronger current is passed through the lamp the filament glows white, and the spectrum is a band of colours ranging from red to blue. There are no breaks in the spectrum; it is a continuous band of colours. This tells us that the glowing filament gives out light of all wave-lengths from red to blue.

Spectra of Glowing Gases

A glowing gas has a different story to tell; it has a different kind of spectrum consisting of bright lines of different colours with dark spaces between; sometimes there are a great many lines. Each of these lines is given by light of a particular wave-length.

Common salt is sodium chloride; that is, it is a compound of the soft metal sodium, and the gas chlorine. Suppose we dissolve some common salt in water, dip a piece of asbestos in the solution, and then hold the asbestos in the colourless flame of a bunsen burner. The flame becomes bright yellow because of the sodium which is vaporized in it. If we examine this flame through a spectroscope we see a spectrum that is almost entirely dark, but with two bright yellow lines close together. These two lines are characteristic of the metal sodium. We should get the same two lines from sodium carbonate. Indeed, if we find these two lines in the spectrum of an incandescent gas we can be sure there is sodium in the gas.

The spectrum of hydrogen contains a bright orange line

and several blue and indigo lines. The presence of thes(lines in a spectrum indicates the presence of hydrogen Other elements also have their distinctive lines, so that a careful examination of the spectra of glowing gases car tell us what elements are present in them.

Diffraction Gratings

Instead of a glass prism, a *diffraction grating* is usec when the spectrum is to be spread out very widely. The grating is made by ruling parallel lines on a sheet of glas: with a fine diamond point. These lines are drawn ver) close together; as many as 40,000 have been drawn to the inch. A smaller number, however, will suffice: 18,000 tc 20,000 lines give good results, and 10,000 to 12,00(lines are commonly used.

A narrow beam of light is allowed to pass through the grating, and a telescope is focused on the slit througt which the light enters. A central image of the slit is seer and on both sides of it the spectrum of the light that enters.

Your own Diffraction Grating

A diffraction grating is of course a very expensive thing, on account of the difficulty of drawing the lines. A method has been found of getting cheaper gratings by pressing the original gratings on celluloid and so obtaining a replica of the original. Even one of these costs about ten guineas. However, there is a "student's grating" which anyone may have. Adam Hilger Ltd., 98 St. Pancras Way, London, N.W.1, will supply it for 4*s*. 3*d*.

You may be disappointed when you first see the grating, but not when you begin to use it. It is a small piece of celluloid mounted between two thin sheets of glass. When you first look through it you see—just what is at the other side.

But hold the grating in a bright light over a dark background. Tilt it a little at a time, and presently you will see, very bright and clear, the spectrum colours pass across it in order.

To see the spectrum of sunlight, hold the grating close

to the eye, and look, not at the sun but below it. The band of colours is very brilliant, and glaring in the yellow and red. Lower down still you may see a second spectrum.

Looking at Spectra

We can use the small grating to examine the spectra of various metals. We really want a bunsen burner, but an ordinary gas ring will do; we adjust the air supply so as to have the flame as colourless as possible.

We put up the blackout, light the gas, and turn it down till there is a small flame. A piece of asbestos is the best thing for putting salts into the flame, but a piece of brick will do. We dip the asbestos in a solution of salt, and examine the flame through the grating. Practically the only colour in the spectrum is the bright yellow. We can test any other salts we have in the same way.

Lines in the Spectrum

When the spectrum of sunlight was well spread out and carefully examined, an odd thing was found. It turns out that the spectrum of sunlight is not continuous, like the spectrum given by the glowing filament. On the contrary

Fig. 16.

it contains a large number of dark lines (Fig. 16). These lines are called *Fraunhofer lines*, because Fraunhofer was the first to observe that some at least of these lines coincide with the bright lines in the spectra of different elements.

It is not easy to see the Fraunhofer lines with the small grating, but it is possible. We can darken the room and admit light through a very narrow slit between the edges of two razor blades. We look at the light which comes through this slit.

Another method is to spread out some dull black material where the sunlight falls directly on it; this is to cut out reflection as much as possible. We polish a fine

needle and fix it upright in the middle of the dull material. We can use a lens to concentrate light on the needle. We examine the glowing line of light on the needle, through the grating. If we have any luck we can detect the dark lines.

What the Lines Tell

The explanation of the Fraunhofer lines was given by Professor Stokes. He heated salt solution in a flame, so that he could have the glowing vapour of sodium, and the bright yellow lines of the sodium spectrum. Then he passed a beam of white light through the sodium vapour, so as to produce a continuous spectrum without the dark lines of the solar spectrum. He now observed the spectrum, *but*, where the two bright lines of the sodium spectrum had been, he saw two dark lines, similar to the dark lines of the solar spectrum.

What was the explanation? We know that light consists of waves, and that each colour has its own wave-length. Glowing sodium vapour gives out light of two nearly equal wave-lengths, and so these two colours appear in its spectrum.

Now when white light is passed through sodium vapour, the vapour takes up, or absorbs, light of its own two wave-lengths. All the light passes through except that of these two wave-lengths, and so there are dark gaps where these two wave-lengths should be.

We see now that there are two kinds of spectra. There is the *emission* spectrum, like that of sodium vapour, which emits light of particular wave-lengths. There is also the *absorption* spectrum given by light which has passed through glowing vapours, so that some of the wave-lengths are absorbed, or removed from it.

The dark lines in the solar spectrum at once become of great importance, because of the extraordinary story they have to tell. The sun is extremely hot, so that its atmosphere contains the heated vapours of many elements. Light from the surface of the sun passes through its own heated atmosphere before reaching us, and so we get dark lines in the spectrum corresponding to the various elements in the sun's atmosphere.

The "Impossible" Made Possible

The great French philosopher Auguste Comte drew up a list of things that man would never by any possibility accomplish, and amongst them he included the attainment of a knowledge of the chemical composition of the sun and stars. In his time—the first half of the 19th century—this might well have been considered an impossibility, for nobody then could have dreamed that the light we receive from sun and stars would tell us of what those bodies are made.

This secret is revealed to us by the dark lines in the solar spectrum. These dark lines, corresponding as they do to the bright lines in the spectra of glowing vapours, prove that the sun's atmosphere contains the same elements as are found in the crust of the earth. Earth, sun and stars are made of the same materials.

The positions of the thousands of Fraunhofer lines have been carefully catalogued by using the scale in the spectroscope, and these lines have been compared with the spectra of the earthly elements. The two strongest lines in the solar spectrum correspond to lines given by the metal calcium which is found in chalk. Next in strength come lines which show the presence of hydrogen and iron.

A New Element in the Sun

One of the early successes of spectroscopic analysis, as it is called, was the observation in the solar spectrum of a group of lines that did not correspond with the spectrum of any known element. It was supposed that these lines indicated a new element, which was tentatively called helium, from the Greek word *helios* = the sun. An element that gives these lines has since been discovered as one of the rarer gases of the earth's atmosphere. Thus we have the extraordinary fact of an element being discovered, or at least suspected, in the atmosphere of the sun before it was discovered in our own atmosphere.

Wave-lengths and Frequency

Instead of talking of the wave-lengths of different kinds of light it is often convenient to talk of their *frequency*.

The two terms are closely related. We know that all light travels at the same speed—186,000 miles per second. In a second a certain number of waves pass a given point, and these waves, end to end, would stretch 186,000 miles. We can have a smaller number of long waves, or a larger number of short waves (Fig. 17).

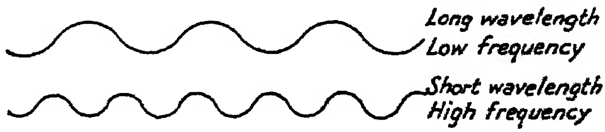


Fig. 17.

The number of waves per second is called the frequency of the light. So we have:

blue: short wave-length, high frequency.
red: greater wave-length, lower frequency.

Beyond the violet we have the *ultra-violet* rays which have still shorter wave-lengths and still higher frequencies. Below the red we have the *infra-red* rays which have still greater wave-lengths and still lower frequencies (Figs. 17 and 18).

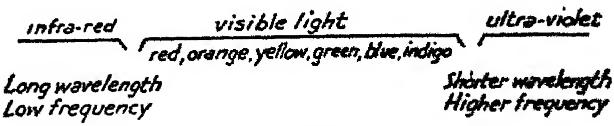


Fig. 18.

Wave-lengths and frequency are two terms expressing the same thing, and we use whichever happens to be convenient for our purpose.

The lines of a spectrum may be wholly in the visible part of the spectrum, or they may extend into the ultra-violet on one side or the infra-red on the other side. How can we know about the lines which we cannot see? The ultra-violet rays have a great effect on a photographic plate, and a photograph reveals them clearly. It is now possible to take photographs with the infra-red rays, so that both ends of the spectrum can be examined. The infra-red lines can also be detected by their heating effect.

The Spectra of Atoms

An atom contains a store of energy. It has a central core with one or more electrons spinning round it at great speed. There are various orbits in which an electron can move, and it can jump from one orbit to another. Each time an electron makes one of these jumps it emits a small packet (a *quantum*) of energy. This quantum of energy appears as light of a particular frequency. So we have atoms, stirred into activity by heating, giving out light of definite frequencies. These are the lines of light that appear in the spectra of atoms. Usually the different kinds of light are mixed; the spectroscope sorts them out into frequencies.

Molecular Spectra

Atomic spectra are comparatively simple. Molecular spectra begin to be complicated, because there are several ways in which molecules can give out quantised energy. that is, energy in quanta, or little packets all the same size, It is the quanta that appear as light.

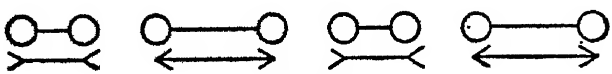


Fig. 19.

First of all a molecule can rotate about an axis. Every time there is a change in the energy of rotation a quantum is emitted. And so we get a *rotation spectrum*. These spectra are in the far infra-red region, and have to be investigated by their heating effect.

In addition, a molecule can vibrate. The simplest case is that of a two-atom molecule; the atoms can move in and out, like an elastic dumb-bell (Fig. 19). Any change in the energy of vibration releases a quantum of energy. So we have vibration spectra. These are in the near infra-red region, and so they can be photographed. They have the lines in the same relative positions as the rotation spectra, but the lines are broadened out into bands.

We can also have electronic jumps, from orbit to orbit,

just as with atoms. The electronic spectra are in the visible and ultra-violet parts of the spectrum, so they can be photographed completely.

What Isotopes Are

One of the most fascinating discoveries about atoms is the existence of *isotopes.* An atom has a heavy nucleus, and a number of electrons whirling round it. The chemical properties depend only on the electrons; the weight depends on the size of the nucleus. In isotopes we have two or more kinds of atoms with identical electrons, but with different nucleii. So we can have two or more samples of an element which are alike in all their properties, except their weight and some properties that depend on weight. They have the same colour, the same smell, they form the same crystals, and the same compounds with other elements.

Isotopes of an element are so much alike that it is almost impossible to separate them. The chemist separates elements by forming compounds which have very different properties; one may be soluble and another insoluble, for example. But the compounds of isotopes are alike in all their chemical properties, so they cannot be separated in this way.

The extra weight of a heavy isotope does give it a slightly higher boiling point than a lighter isotope; it seems as if we could separate the two by distilling; but the difference is usually very small, and the method is difficult. A more hopeful method is to let a gas diffuse through a porous material. The lighter isotope goes through more quickly, so that we have a lighter gas on the far side of the partition, and a heavier gas on the near side. After repeated diffusions, this method has resulted in a partial separation of isotopes: a bigger concentration of the heavier isotope in one sample of the gas, and of the lighter isotope in the other.

Spectrum analysis can show the existence of isotopes even when we cannot separate them. Chlorine has two isotopes; one has an atomic weight of 35, and the heavier isotope an atomic weight of 37. Ordinary chlorine is a

complete mixture of the two; it has an atomic weight of 35·46. There is roughly one part of the heavier isotope to three parts of the lighter.

Now chlorine gas consists of molecules each of which is made up of two atoms. We can have three kinds of molecules: $^{35}Cl_2$ (two atoms of the 35 isotope), $^{35}Cl\,^{37}Cl$ (one atom of each isotope), and $^{37}Cl_2$ (two atoms of the 37 isotope). We know that the atoms vibrate, and the rate of vibration depends partly on the weight of the atoms. So we have three different vibration spectra, one for each kind of molecule. The lines are close together, but nevertheless they can be distinguished. The differing brightness of the lines shows the proportion of each kind of molecule present in the gas.

Effects of Temperature

Increase of temperature has little effect on atomic spectra, but it does cause a change in molecular spectra. The general effect is to intensify the lines over towards the ultra-violet.

Experimental work on spectra has been carried out at very high temperatures by three different methods, the substances to be examined being heated in furnaces, in electric arcs, and in electric sparks.

In the electric arc the terminals are made of the substance which is being examined. A direct current is passed through the terminals whilst they are in contact. The terminals are then separated a short distance. The current is carried across the gap by hot particles of the terminals in vapour of this substance. The temperature reached in the electric arc is about 3600° C. This temperature is high enough to vaporise most of the elements.

A still higher temperature is reached in the electric spark, where an alternating current sends a spark between terminals of the substance being examined. It has not been possible to attain in the laboratory a temperature as high as the surface temperature of the sun, which is about 5800° C.

It should be clear from this that spectra can tell us something about the temperatures of bodies that emit light.

They should also be able to tell us whether material through which light passes exists as atoms only, or whether the atoms are combined into molecules.

What the Stars are Made Of

The sun gives so much light that its spectrum can be well spread out, and examined in great detail. It is a more difficult matter to examine the small amount of light that comes from a star. Fortunately, there is one great aid to the examination of stellar spectra: these spectra can be photographed, and the plates can be exposed for a long enough time to obtain clear prints.

The stars have been classified into nine groups according to their surface temperatures. The hottest of all are called O stars, and the coolest N stars; the sun is half-way along the temperature scale as a G star. The whole sequence of stars is rather oddly lettered: O, B, A, F, G, K, M, R, N.

The hottest of the stars show very strong hydrogen and helium lines in their spectra, and the lines of hydrogen are still strong as far down the scale as the G type to which the sun belongs. The spectra of metals begin to show in the F stars; they are stronger in G stars, and are very prominent in K and M stars.

The hottest stars show atomic spectra and never molecular spectra. This is only to be expected. Many compounds are readily broken up into simpler compounds or even into atoms, by heat. The high temperature sets the molecules vibrating with great rapidity, and ultimately shakes them into separate atoms. Hence the hottest stars consist only of atoms; it is only the cooler stars that give molecular spectra. There are indeed some traces of compounds in the cooler parts of the sun and K stars show still more; but it is not till we reach the R and N stars, at the cooler end of the scale, that compounds become important. The R and N stars give the spectrum of cyanogen, a poisonous compound of carbon and nitrogen. They also show the spectra of hydrocarbons; these are the kind of compounds of hydrogen and carbon that are found in paraffin.

Common Stars

The most common types of stars are B, A, F, G, K and M. The stars of Orion, with the exception of Betelgeuse in the top left-hand corner, are B stars. Like other B stars, and A stars too, they are white. Sirius is the best known of the A stars; it is the brightest of all the stars; the belt of Orion points down to it. Stars of the A type (hydrogen stars) are sometimes called Sirian stars, or simply Sirians. The F stars are pale yellow in colour; the Pole Star is one of them. The G stars, like the sun, are yellow; they are often called sun-stars. The K stars are reddish, and the M stars distinctly red. Arcturus is a K star; it is the bright star seen when the curve of the handle of the Plough is continued outward. Antares and Betelgeuse are M stars. Antares is the bright red star in the Scorpion.

People on Planets?

Everyone wants to know whether the planets are habitable. Can people live on Mars? Do people live on Venus? What about Jupiter? We are always asking these questions, and the usual answers we get are the imaginations of novelists. Some of these are silly, some are amusing, some are intriguing; but none of them are convincing.

Has spectrum analysis anything to say? At first it might be thought that spectrum analysis would give no information about the planets, since the planets merely reflect the sunlight that falls on them. And yet, on second thoughts, we *might* expect something. Some of the light that falls on planets may be reflected from clouds, and may reach us as nothing more than reflected sunlight. But, after all, some of it may get through to the solid surface of the planet, and it may be reflected back through the atmosphere of the planet. It is possible, therefore, that the light which reaches us may be able to tell us something about that atmosphere; and life as we know it depends on that atmosphere.

Our Nearest Neighbour

Venus is our nearest neighbour amongst the planets, and not far short of the size of the earth. Apparently it rotates in a little less than 24 hours, though it is difficult to be sure, because a dense atmosphere hides surface features. Near the equator it must be uncomfortably warm, but apart from atmosphere, there seems to be nothing to preclude the existence of life, at any rate on some parts of Venus. The absorption spectrum of Venus contains lines that show the presence of a lot of carbon dioxide in the atmosphere. This suggests that there is little or no plant life on the planet. If there were plants they would take up most of the carbon, just as they do on the earth. And of course the absence of plant life precludes the existence of animal life, which is ultimately dependent for its food on plants. On the whole, some form of life seems possible (though hardly probable) on Venus; and even if it is non-existent now, it is at least a possibility of the future.

Scorched or Frozen

Mercury seems to be too close to the fire even for a hot-house existence; any patch on its surface gets more than six times as much light and heat as a corresponding spot on the earth. No one seems to know how long it takes to rotate on its axis. It is even suggested that it may, like the moon, rotate in the same time as it revolves. If so, it presents one side perpetually to the blasting heat of the sun, while the other side faces the equally blasting chill of perpetual night. And the sun seems to have stolen Mercury's atmosphere. Altogether a very uncomfortable planet.

Are there Martians?

Mars is smaller than the earth; the whole mass of the planet is not much more than a tenth of that of the earth. But it is not too small to be able to hold an atmosphere. It is half as far away again from the sun as the earth, so that it gets less than half as much light and heat as the earth. The Martian year is nearly twice that of the earth,

687 days. The day is 24 hours 37 minutes, which is much the same as our own day. The axis has about the same inclination as that of the earth—nearly 25°—so that there are distinct seasons. The seasons are twice as long as ours on account of the longer year, so that there is time for heat to accumulate in summer. The surface of Mars shows distinct seasonal changes, especially in caps about the poles, which may be ice. The spectrum shows the presence in the atmosphere of free oxygen. So the rather thin atmosphere of Mars appears to have both oxygen and water, the two things most urgently necessary for life. There may be some form of life on Mars, even though it may be very rudimentary.

The Poison Gas Planet

Jupiter is a big planet, but it is not very dense. It has the same density as the sun, which has a quarter of the density of the earth. Jupiter has about 1300 times the volume of the earth, and 314 times its mass. It gets little heat and light from the sun, a mere twenty-fifth or so of what we get. The axis is inclined at only 3°, so that a possible Jovian would have little to excite him or worry him in the way of seasons. However, the spectrum definitely declares life on Jupiter to be impossible. There is a dense atmosphere heavily laden with ammonia and methane (one of the hydrocarbons). No life could exist in that poisonous atmosphere.

We need hardly consider the possibility of life on Saturn, Uranus, Neptune and Pluto. They are so far removed from the sun as to be chill and dark. Day, at the best, cannot be much more than a gloomy twilight.

As for the moon, it has shed any atmosphere it ever had.

6.—WINDMILLS AND TURBINES

Can you answer these questions?

Why do the sails of a windmill rotate?
How are the sails kept facing the wind?
How does a modern windmill differ from the old-fashioned mill?
For what three purposes can a bladed wheel be used?
How is a coal-mine ventilated?
How is a forced draught produced?
How does a centrifugal pump work?
What is the essential part of a vacuum cleaner?
Why is the screw of a ship always placed at the stern?
How is electric light obtained from a waterfall?
What is a Pelton wheel?
How do low-pressure water-turbines work?

MOST people have made and used the old paper mill. It is one of the easiest toys to construct, and it can be very instructive.

The only materials needed are a sheet of paper, about eight inches square, a pin, and a small rod (Fig. 1). We make the paper into a square, and we draw the diagonals of the square. We cut along the diagonals from each corner in turn, to within half an inch or so of the centre. We take one of the cut corners and fold it across the centre. We take alternate corners all round the square, and fold each across the centre. Altogether four corners are thus folded across. We now push a pin through the four corners folded over, through the centre of the square, and into the rod. The paper mill is then complete.

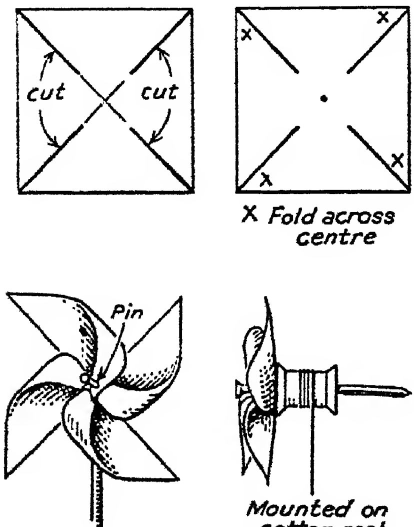


Fig. 1.

The Relative Wind

If there is a wind, we can hold the mill so that the wind can blow on it and set it spinning rapidly. If there is no wind we can run with it and again set it spinning. We get the same effect by holding the mill in the wind as by running with it so as to press it against the air. As usual, it is the relative movement of mill and air that counts. This is another case of the " relative wind ".

We could mount the paper mill on an axle, and use it to do some kind of work, like raising a weight. Anyone who cares to try this will quickly find the limitations of the

little mill. The weight would have to be very light indeed; the mill itself is so light that it has very little momentum to carry it past awkward points where it happened to catch. We can mount the mill, with paste, on a cotton reel, however. A paper mill made of stout paper will readily turn the reel on a thick nail used as an axle. The reel acts as a small flywheel, and helps to keep the mill from catching. Thin string may be attached to the barrel of the reel, and used to raise a small weight.

A Modern Windmill Toy

A much more effective toy mill can be made by imitating the modern kind of windmill.

We want a sheet of strong thin cardboard of fairly good quality; strawboard will do, but it is not so good for this purpose as white cardboard. We cut out a circle 9 inches or so across (Fig. 2); and draw on it another circle with the same centre, with a radius of an inch or rather less. We divide the circle into eight equal parts by radii, and cut along each radius as far as the inner circle.

Next we find the middle point of the arc of each segment, and score a line with the point of the scissors, from the mid-point of one of the arcs, to the point where the cut line meets the inner circle; we do

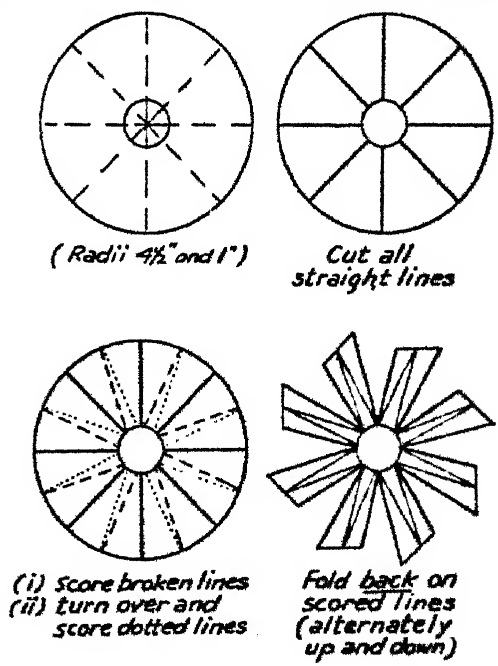


Fig. 2.

this at one side only. We treat the other segments in the same way, taking care that all the scored lines run in the same direction.

We now turn the card over, and make similar scores on the other side, but going from the middle of each outer arc to the opposite end of each inner arc. These lines are shown dotted in the diagram.

We fold *back* along each of the scored lines, so that the edges go alternately up and down. We push a thick nail through the middle of the wheel, give it a few spins so that it turns readily on the axle, then hold it facing the wind. Even a light wind will make it spin; a fairly strong wind will make it spin with great rapidity.

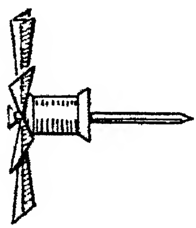


Fig. 3.

We can mount this wheel also by tacking it to a cotton reel (Fig. 3). It will run smoothly on a long nail which has just enough clearance to allow the reel to turn easily.

We can also mount the wheel between two uprights (Fig. 4). For the base we want three pieces of wood 2 inches wide, 6 inches long, and half an inch thick, more or less. We put two pieces on their long edges, and parallel. The third piece is put on its flat side lengthwise between the other two, and flush with

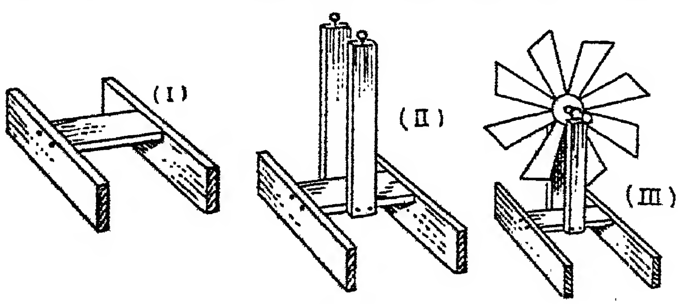


Fig. 4.

their tops at the middle point. The base is nailed together in this form.

The uprights are two pieces of wood an inch wide, 6

inches long, and half an inch thick. These uprights are nailed in position halfway between the two side struts.

We fix steel eyes in the top of the uprights, put the wheel in place between them, and hold it there with a large nail as an axle.

Why the Wheel Rotates

Let us think of the wind pressing on one blade of the wheel (Fig. 5). The wind pressure would drive it backward if it were free to move backward, but it is held by the axle. Instead, it pushes the blade out of the way, sideways. As the wind is continually exerting this sideways pressure, the wheel continues to rotate. All the other blades are

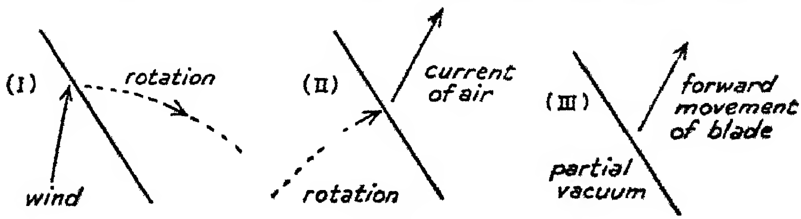


Fig. 5.

acted on in the same way, so they are all pressed sideways in the same direction.

We can always tell in which direction the wheel will turn by noting how the blades are set. We have only to see in which direction the blades would be pushed out of the way by the wind. Incidentally we may note that the wheel will rotate in the same direction if we turn it round to face the wind from the other side: the blades slant in the same direction whichever side is towards the wind.

If we want the wheel to turn in the opposite direction we must either wait for a wind in the opposite direction, or reverse the slant of the blades—turn them up where we previously turned them down, and turn them down where we turned them up.

Turning the Wheel

One of the advantages of mounting the wheel between uprights is that we can readily make it spin. We wind string round the cotton reel to which the wheel is attached,

and then draw it out rapidly, as in spinning a top or the flywheel of a gyroscope.

One of the effects of spinning the wheel is that it drives a stream of air before it. Each blade strikes the air in front of it and drives it forward. The direction in which the current is driven is the same as the direction of the wind which would drive the wheel (Fig. 5).

Now the current of air that is driven back must come from in front of the wheel. The turning wheel is therefore tending to create a partial vacuum in front of it. Either air flows in to replace the air driven back, or the wheel is driven forward by the greater pressure behind. The turning wheel may create a current of air, if it is fixed by an axle; or it may be pushed forward and so act as a propeller, even if it only propels itself.

We have to keep in mind these three ideas about a bladed wheel (Fig. 5): (i) it can be driven round by a current of air; (ii) it can create a current of air in the same direction if it is turned in the same direction; (iii) it can move forward when it is set spinning, and so act as a propeller.

We may add that if the direction in which the wheel is spun is reversed, the direction of the current is also reversed, and so too is the direction in which the wheel advances if it is free to move.

The Old Windmill

The old-fashioned windmill was the same in principle as the toy windmill. Its four great sails (Fig. 6), set at an angle to the wind, provided the motive power. Their massiveness made a flywheel unnecessary; the weight of the sails itself served as a flywheel. The purpose of the mill was to turn the huge upper millstone, and we will see how it was adapted to serve that purpose.

The most important adaptation is a means of keeping the sails facing always into the wind. This is an obvious necessity; a cross wind would cause the mill to work inefficiently, as may readily be seen by turning the toy mill half on to the wind; a wind from behind would certainly turn the sails in the opposite direction, but a strong wind

from behind might blow the mill over. Indeed, overturning was a serious danger to the old windmills; a sudden change of wind might jam the sails and prevent them turning to face the wind; the mill would then be in danger from sudden blasts.

In order to keep the sails facing into the wind, the upper part of the mill to which the sails are attached was made with a central vertical axle; it could rotate about this axle on wheels. Sometimes the mill was levered into position to face the wind; this method was unsatisfactory, because there might be no warning of sudden changes in the wind. More often the sails were turned by means of a small wheel with vanes which was set at right angles to the sails. When the sails were 90° from facing the wind, that is in a cross wind, the small wheel faced right into the wind, and it then operated most powerfully to turn the sails. As the sails turned more and more into the wind the wheel acted less and less strongly, and finally it ceased to act when the sails faced the wind and the wheel was in line with it. This idea was introduced into mills in 1750.

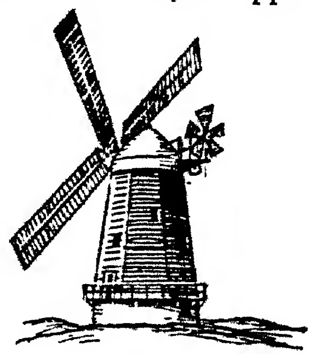


Fig. 6.

The second important adaptation is a means of enabling the sails to act equally well in light and strong winds. The sails are not solid, but are made with slats that can be raised or lowered. The slats are weighted, so that usually they hang straight down. A light wind is not strong enough to raise the slats, and the sails present to it a practically unbroken surface. In stronger winds the slats are blown back, and the surface which meets the wind is thus reduced. The reduction is proportional to the strength of the wind, so that the general effect is to equalise, more or less, the pressure on the sails of light winds and strong winds.

The axle on which the sails turn is horizontal, and the axle on which the upper millstone turns is vertical. The

change over from horizontal to vertical is made by means of bevel gears (Fig. 7). The great sails turn slowly, but powerfully. We can therefore gear the movement down by means of gear wheels, so as to obtain quicker but less powerful movement.

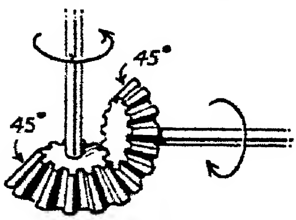


Fig. 7.

Some of the old windmills had arms 30 or 40 feet long; the sails were 5 or 6 feet wide and extended over all but a sixth of the arms.

A mill with four arms 30 feet long, and sails 5 feet wide might be expected to supply 1¼ horsepower in a wind of 10 miles per hour.

Modern Windmills

A great many windmills are still in use. They are commonly used in flat countries, like Holland and the eastern counties of England. In flat countries we often get strong steady winds; that is just what is wanted to drive a windmill. In hilly countries the hills divert winds and cause sudden changes; that is just what is not wanted.

Windmills are best suited for slow, heavy operations that can be carried out at any time; just as barges are suited to heavy traffic where haste is not important. The grinding of corn can be carried out when the wind is favourable; a few days' delay is not important. In Holland and other flat countries windmills are used to pump water from low-lying land into canals and rivers; this kind of work also can wait for favourable winds.

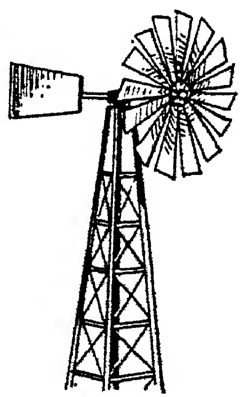


Fig. 8.

Most modern windmills are made on the improved plan of the second toy mill. Instead of four large sails, they have a great many blades set at an angle round a wheel (Fig. 8). We have already seen that these mills are much

more efficient than the older types. The angle at which the blades are set to the wind can be changed so as to meet varying conditions. The angle is large for light winds, and small for strong winds. A single large vane, projecting behind the wheel, is sometimes used to keep it facing into the wind. The new mills are often used to drive dynamos, and so to change the rotation of the wheel to electric power which can readily be distributed wherever it is wanted. Some of the power can also be used to charge accumulators, so that power may be available when the mill wheel is not turning.

The Electric Fan

Now let us look at some of the modern inventions that depend on the principle of the mill toys. The electric fan is probably the simplest of all these inventions. It is actually a little mill wheel with two or more blades (Fig. 9). The blades may be simply set at an angle, but the fan works more efficiently if they are bent, in the same way as an airscrew, with the greatest angle at the hub, and the smallest angle at the tips.

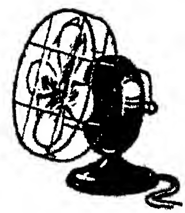


Fig. 9.

The fan is rotated by means of an electric motor. As it is not free to move forwards or backwards, its rotational energy is used up in driving a stream of air. The fan may be used to create a current of air in a room, and so to liven up the atmosphere. A small device is usually added to turn the fan to and fro in an arc of a circle, and so to spread the air current over various parts of the room.

An electric fan may equally well be used for ventilating a room—that is, for ensuring a supply of fresh air from outside. For this purpose a circular window is made, usually high up in one of the outer walls. The fan is made to rotate in the open circular space, and it drives a stream of air into the room from outside. The air-stream can be directed so as to avoid causing draughts in the lower part of the room.

A fan can also be used to draw air out of a room. For this purpose we have only to rotate the fan in the opposite direction. An inward working fan drives air into the room, and so causes a small increase of pressure inside. The additional air forced in escapes again through chimneys and spaces round doors and windows. An outward acting fan, by sucking air out of the room, reduces the air pressure; fresh air flows in through various crevices and helps to restore the balance.

Ventilation in Mines

We are not solely dependent on electric motors for driving ventilating fans. A large fan can be driven by means of a steam engine or other source of power. Large fans can be rotated at high speed, and can cause powerful streams of air at considerable pressure. Large centrifugal fans are used to drive air down the shafts and through the galleries of mines. Below the ground there may be miles

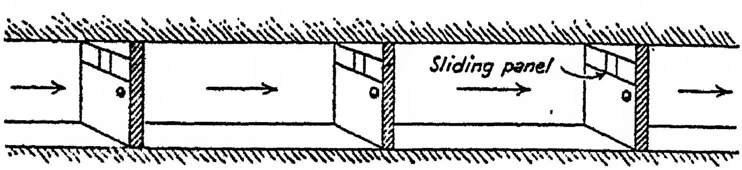


Fig. 10.

of galleries; every part of these has to be ventilated to prevent the accumulation of harmful gases. Air must be driven down under the pressure obtained by using a large fan. The pressure may be as much as two inches of mercury, which is equivalent to one pound per square inch, or over a hundredweight per square foot.

At the bottom of the ventilating shaft the air which is driven down is spread out into a wide space round the lower end of the cage, and into a number of passages. The pressure is decreased, but it is still very noticeable. The stream of air flows along the main passages of the mine until it reaches the outlet shaft. The air has to be directed to prevent it taking short cuts, and so missing some of the galleries altogether. This is especially necessary in side-

galleries connecting the main passages. Such passages often have doors at intervals (Fig. 10), which are kept closed by the increased air pressure on the side from which the ventilating current comes. Even a small pressure difference becomes large when it is multiplied by the large area of a door. A door 6 feet by $3\frac{1}{2}$ feet has an area of 21 square feet. Even a tenth of an inch of mercury exerts a pressure of $\frac{1}{20}$ pound per square inch, or about 7 pounds per square foot, and that is equal to 147 pounds distributed over the door.

The total pressure on one of these doors is so great that it is often almost impossible to open it by pulling. However, each door has a small sliding panel, and when this is pushed aside, air rushes through and equalises the pressure on the two sides; the door then opens easily, almost of itself. Before we go on we have to be sure to close the panel again; if the panels were left open all along the gallery, a short cut would be provided for the air stream, and the ventilation would go wrong.

Air pressure between two doors increases until it is balanced by leakage round the door. Each time a door is opened some air passes from the higher pressure side to the lower, so that there is always sufficient ventilation in the side galleries.

Forced Draughts

Fans can be used as a means of producing forced draughts. In a furnace there is a "natural draught" caused by the hot gases which are forced upward by heavier cold air pouring in below; this is the kind of draught that keeps an ordinary household fire burning. The term "natural draught" is commonly used for such draughts, though they are artificially produced by building chimneys. Such a draught does very well for a household fire, but it may not be sufficient to produce the fierce heat needed in many furnaces, in the furnaces used for smelting iron, for example. The natural draught can be reinforced by using powerful fans to drive air under pressure into the lower part of the furnace (Fig. 11). A furnace through

which a blast of compressed air is driven is called a blast furnace.

This is not the only way in which a forced draught can

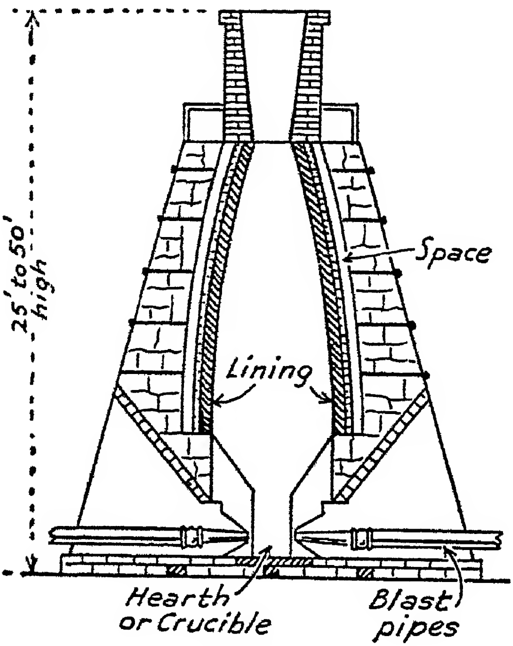


Fig. 11.

be produced. A jet of steam is sometimes allowed to escape upwards in a chimney. Air is thus drawn upward, and a draught produced.

A Fan as a Pump

A fan can be rotated to give an outward current of air just as easily as to give an inward current. It can therefore be used to draw air out of a container, and so to produce a partial vacuum. The extent of the vacuum produced depends partly on the speed with which the fan, here used as an air pump, is rotated. There is a limit to what can be done with any fan. As the pumping goes on the pressure inside the container decreases, while the pressure

outside remains at atmospheric; we are therefore working up towards an unbalanced inward pressure of 15 pounds or so per square inch.

A different form of fan is generally used in air pumps (Fig. 12). Curved blades are fastened radially to an axle. Air is allowed to enter through a pipe round the axle. As it enters it is flung outwards by centrifugal force, and more air is drawn in. The air flung outward may be allowed to flow away, or it may be directed into a pipe, to be used for a forced draught or some similar purpose.

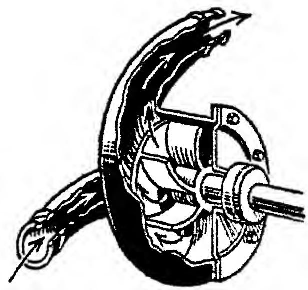


Fig. 12.

A fan of this kind can be used just as well for ventilating purposes.

Centrifugal Pumps

The kind of fan just described is sometimes called a centrifugal pump. Such pumps can be used for driving streams of water as well as air. In order to make them more efficient it is usual to have guide blades round the rotating blades. The guide blades direct the water in the direction in which it is to go.

Small centrifugal pumps are used to produce the circulation of water in motor-car radiators, to keep oil flowing in pipelines, and for other similar purposes.

The Vacuum Cleaner

The vacuum cleaner is an astonishing application of the fan, or centrifugal pump; it is astonishing because of its simplicity and neatness. The essential part of it is a small fan driven at high speed by an electric motor (Fig. 13). The fan is fixed in a tube, and it produces a strong inward draught along this tube. The end of the tube is passed over carpets and furniture, and the draught carries

in with it dust and other light particles. The dust passes through the tube to a bag, where it is trapped; the bag is made so that it can be opened and emptied from time to

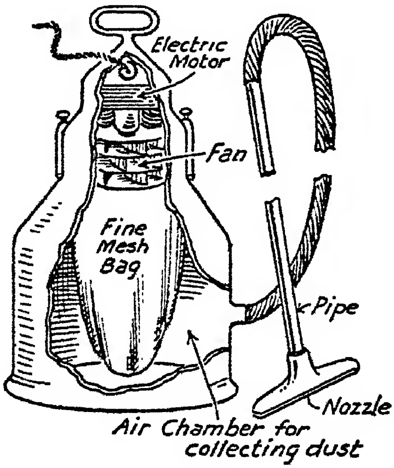


Fig. 13.

time. The efficiency of the machine depends on the neatness of the fittings, and the power of the fan or pump; neatness in the fittings ensures that there are no leakages and a powerful fan ensures a strong current of air to draw in dust.

A Fan as Propeller

Suppose we have a fan, with suitably curved blades, rotating at high speed. We know that it can drive a strong current of air behind it, and that the faster the fan rotates the stronger is the current of air. That is to say, the current of air is moving backward relatively to the fan. So far as fan and air are concerned, the effect is the same as if the fan were moving forward through the air. Indeed, if the fan were suddenly released from its moorings it would cut forward through the air. Its weight would probably carry it down rather quickly, and it would pitch forward on its nose. Nevertheless, we should have the

fan acting as a propeller in drawing itself forward through the air. It might be an inefficient propeller, but there would be at least a little forward movement.

The airscrew is an adaptation of the fan idea to suit aeroplanes (Fig. 14). It operates in very much the same way as a fan. When it first begins to rotate it drives a strong current of air backward, and it continues to do so while it is rotating. But it is free to move forward, and it begins to cut its way through the air in front of it. It drags the aeroplane after it, and so acts as a propeller. Airscrews are sometimes, but not often, attached to the back of aeroplanes. In this position they have a similar effect in driving the plane forward.

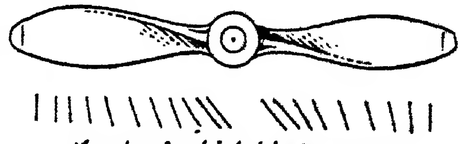


Fig. 14.

Screws on Ships

The idea of using fans as propellers was first of all applied to ships. Steamships came into existence soon after the beginning of the nineteenth century, but the use of fans, or screws, came considerably later. The earliest steamships were driven by paddle-wheels. One of these paddle-ships had a huge wheel on each side amidships; the wheel had blades set round the rim like an undershot water-wheel, and it acted very much like an undershot water-wheel in reverse. We know how an undershot water-wheel is driven round by a strong current of water flowing under it and striking the blades. If the wheel is rotated it drives a current of water backwards: the current moves backward relatively to the wheel. Also, if the wheel is free to move it cuts its way forward through the water. That is the constantly recurring idea of relative motion, and that is how a couple of paddle-wheels were able to drive a ship across the Atlantic Ocean.

The old paddle-steamers were clumsy contrivances (Fig. 15). The great width amidships, where the paddle

wheels were, slowed down their speed, and robbed them of the grace of screw ships. Nevertheless they succeeded in doing their jobs; they had it all their own way for the first thirty years of steam navigation, between 1807 and 1837. In the latter year Captain Ericsson produced a small steam vessel driven by a kind of fan or screw. That was the beginning of a slow change over; the screw gradually drove out the paddle-wheel, except in the kind of small ships that are used for summer excursions.

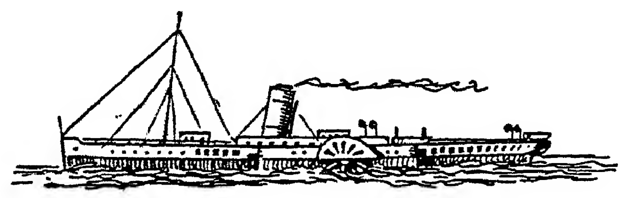


Fig. 15.

For nearly every purpose the screw is much more efficient than the paddle-wheel. It works on the same principle as the fan, though its construction is different because of the different conditions in which it has to work (Fig. 16). The blades have to press on the water with sufficient force to drive great ships forward at high speed; and they have to be powerfully constructed, so as not to break under the enormous strains to which they are subjected. The screws used on ships are wider than the airscrews used on aeroplanes; but the form is essentially the same—a gradual increase in the angle at which the screw meets the water, from the tips to the propeller shaft.

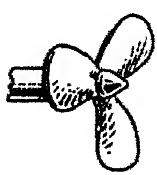


Fig. 16.

Experiment and Economy

A lot of experimental work was done before the present efficiency of screws was evolved. It was found that a small number of propeller blades is preferable to a large number. In one of the early experiments a ship was fitted with two four-bladed propellers, making eight blades

in all. With these propellers she developed a speed of 16 knots from engines expending over 6000 horse-power. Two blades were afterwards removed from each propeller, leaving four blades only. The engines were able to drive the ship at the same speed of 16 knots, but with an expenditure of only about 4000 horse-power. Thus it turned out—a rather curious fact—that a third of the original power had been wasted in turning the four extra blades through the water, without any advantage in increased speed.

Why the Screw is Behind

The airscrew of an aeroplane is usually, but not always, placed in front. It is a matter of experience that it acts more efficiently in that position, though experiments are still being carried out with planes having the airscrew at the tail.

On the other hand, the screw of a ship is always placed at the stern. There are very good reasons for this and very interesting reasons too. As well as pulling the aeroplane forward, the airscrew drives a stream of air backwards. We find the same idea recurring: the screw drives the ship forward, and drives a current of water backwards. The energy that goes into moving the water is wasted. It would be a splendid economy to reduce this waste, but we have to be careful not to introduce a greater waste at the same time. It is highly improbable that the wasteful movement of water can be entirely cut out, but it can at least be reduced.

Here is one way in which waste is reduced. Everyone who has watched a ship must have noticed that it carries some of the water forward with it; friction between the water and the sides of the ship is sufficient to cause this. The width of the mass of moving water increases from the bows backwards; at the stern there is a thick belt of water moving forward with the ship (Fig. 17). This of course is another source of waste: it is no part of the job of a liner to keep the Atlantic Ocean moving.

Now, suppose we balance one kind of waste against the

other. We place the screws at the stern, where they press on the forward moving water. The screws bring the moving water, more or less, to a standstill, and so we recover at the stern the energy that was expended at the bows.

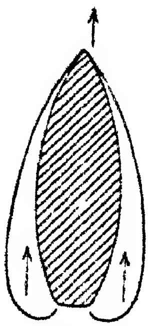


Fig. 17.

That in itself is sufficient reason for placing the screw, or screws, at the stern; but there is another reason. We want the flow of water past the ship to be as smooth and even as possible; any disturbance decreases the speed, or increases the expenditure of energy necessary to maintain the speed. A screw in the bows would have the unfortunate result of causing a considerable disturbance of the water where it is least wanted. That is another reason why the screw is never placed there.

A Toy Turbine

A toy similar to the windmill, but worked by water, may be made from a piece of thin tin. This toy is a kind of small turbine (Fig. 18). We cut out a circle of tin,

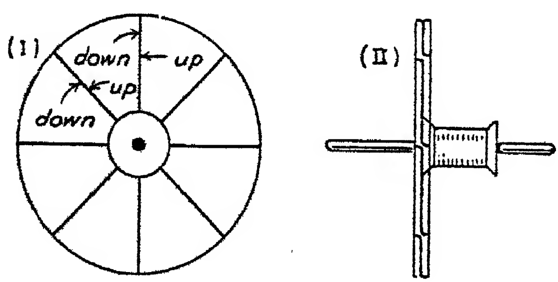


Fig. 18.

about five or six inches across. We rule it off into eight equal divisions by lines through the centre of the circle. We cut along the lines to within three-quarters of an inch of the centre. We punch a small hole at the middle of the circle; this hole should be not less in size than the hole in a cotton reel.

We nail the circle of tin on top of a cotton reel, and evenly over the middle. We turn the cut edges of the tin up and down alternately, one edge up and one down at each cut. We fix a small rod through the central hole in the reel; this rod should project about an inch above and five inches below; it should fit tightly.

We now want a stand to hold the little turbine (Fig. 19). We cut a piece of batten, about six inches long, and we fix it upright on a wooden base. We cut two pieces of batten, each about four inches long, and we fix them to stand out from the upright; one is fixed at the top of the upright, and the other about three-quarters of an inch from the

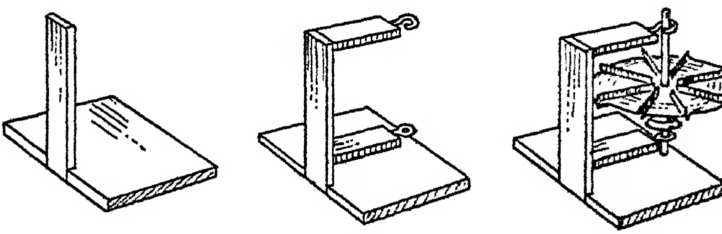


Fig. 19.

base. We want a steel eye in which the axle of the turbine will turn, and a small hook of the same size. We fix the steel eye in the outer edge of the lower support, and the small hook in a similar position in the upper support.

The axle of the turbine is put through the steel eye and the hook, with the circle of tin below. The lower end of the cotton reel should be just clear of the wooden support, so that the turbine can turn without touching this. We have to see that the turbine can turn readily; small adjustments to the axle may be necessary.

Water has to be poured downward on the turbine. It may be poured from a jug, but a better effect is obtained by using water from a hose pipe or a water tap. The little turbine spins merrily as the water runs through it. Any small imperfections seem to be suddenly wiped out as it spins in dazzling light. It is advisable to work the turbine in a bath, or in the open, as there is apt to be a lot of splashing from the edges.

The idea of relative motion comes into all these things. A stream of water through the turbine makes it spin; and if the turbine were shut up in a tube it would work more efficiently, and without waste of power by splashing. If we could reverse the turbine, use some sort of engine to turn it in the opposite direction, then we could use it to drive a stream of water in the opposite direction. We should have, in fact, a rotary pump.

Electric Light from a Waterfall

In a village in the north of Yorkshire—where I used to stay—all the cottages had electric light, and electricity was extraordinarily cheap. It reached us along wires carried at the tops of poles, like small telegraph poles. If you followed the poles you came eventually to a small power-house hidden away amongst trees at the foot of a waterfall.

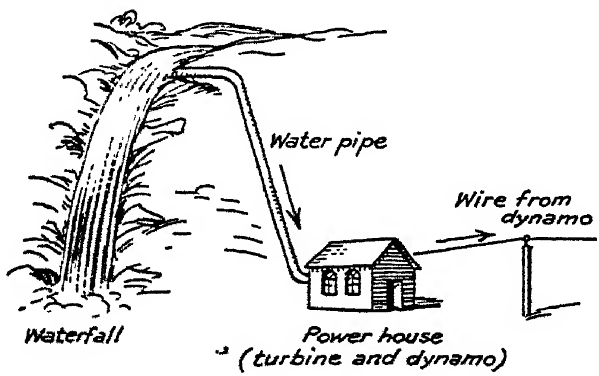


Fig. 20.

At the top of the fall was an unobtrusive pipe which carried part of the water of the fall down to the power-house (Fig. 20). Usually there was no one at the power-house; there was no need for anyone to be there.

What happened was this: the water descending from above the fall set the wheel of a turbine spinning; the spinning axle of the turbine was used to turn the coils in a dynamo; the energy of the spinning coils was thus turned

to electric current; and finally the electric energy was changed to heat and light in the lamps.

That was of course a very small installation. In various parts of the world there are great power-houses for changing the energy of falling water to electric energy. Turbines can be run with water falling from a height of a few feet only, but far greater power is obtained when the water falls from a great height. Power-houses at the Niagara Falls supply hundreds of thousands of horse-power which is used for heating and lighting and running great electric motors. Norway and Switzerland have numerous waterfalls supplying cheap electric power.

We may note in passing that the production of cheap aluminium depends on cheap electric power. It was the development of water-power that made possible the production of aluminium in mass.

Water Turbines

There are several types of water turbine, some of them suited to water falling from a low level, and others to water falling from a high level.

One kind of turbine is really a very carefully constructed undershot wheel which is used when the water pressure is high. The stream of water may be admitted to the wheel from the top or from the side. In both cases the water strikes two or more of the vanes, and so drives the wheel at great speed. Waste is reduced by having the whole apparatus enclosed in a casing.

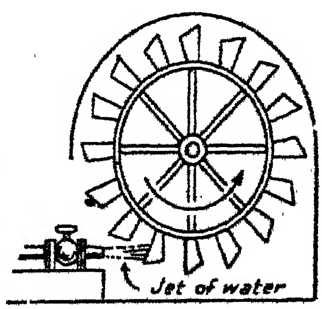


Fig. 21.

In the Pelton wheel (Fig. 21) the blades are cup-shaped, and a jet of water striking on them drives the wheel at great speed. The Pelton wheel has been used with a "head" of as much as 2000 feet; the pressure is equal to the pressure of water at a depth of 2000 feet. This is an

enormous pressure. A cubic foot of water weights $62\frac{1}{2}$ pounds. 2000 cubic feet weigh $62\frac{1}{2} \times 2000 = 125{,}000$ pounds = about 55 tons. So the pressure is about 55 tons per square foot. This is about 60 atmospheres. A jet of water issuing at such a pressure is like a solid bar. A stick may be broken across it; a wooden box thrown on it may be tossed to a distance of 200 or 300 yards.

The turbines used with low-pressure water, heads of 20 or 30 feet or less, are of two kinds. In one kind the water is admitted at the middle of the wheel, and in the other at the outside. When water is admitted at the centre the middle part of the wheel is fixed; it has curved guides which direct the water on to the vanes on the outer, moving part of the wheel. The guides direct the water so that it strikes the vanes as nearly as possible at right angles.

In the second type of turbine the moving part of the wheel, with curved vanes, is at the middle. Round this is the fixed part, with curved guides to direct the flow of water on to the vanes. Water is admitted from the outside, and is directed on to the vanes.

The axle of the revolving wheel may be either vertical or horizontal. When the axis is horizontal water is admitted to the wheel from the side. The turbine wheel usually rotates at high speed. The revolutions can be geared down, if necessary, to slower and more powerful rotation. The usual practice is to use the rotation to turn the coils of dynamos, and so to transform the energy of the falling water into electric energy which can readily be distributed to houses and factories.

7.—THE INVENTOR'S JOB

INVENTING is a most practical business. Some sort of dreaming may suggest "If only we could——," "If only we had——," but after that we have to get down to brass tacks. The inventor does not live on sudden, great inspirations. The central idea may be that, but it is the little details that make the vague dream a practical possibility.

We have been looking at inventions where the necessary things were quite well known. All the interested people knew the things that were needed in order to have moving pictures on the screen. The work of the inventor was to find a practical way of doing this, and a way of doing that. As it happened celluloid film was available, but paper could have been used. With paper the details would have had to be different, but the general idea would have been the same. We should have had the lamps on front of the moving film instead of behind it, and the picture would have been projected by reflection.

Every point in the apparatus had to be thought out detail by detail. The idea of having the film punched with holes at the sides so that it could be threaded over a sprocket wheel may seem obvious to us because we are familiar with it. But someone had to think of it first. How big should the picture be? The reel of film should not be too bulky, but on the other hand a very small picture might give a poor projection. We can look for the answer by experimenting with still pictures in a projector.

There are various ways of getting intermittent movement. We have examined the maltese cross method; it is an interesting and remarkable invention in itself. It is not easy to see how anyone got even an inkling of such an invention. It may have started with the interrupted cam; then the pin may have been added; and slots for the pin to work in may have suggested the maltese cross form. However one analyses the little gadget, it remains a remarkable achievement.

Perhaps a little more obvious than the maltese cross is the idea of having a revolving wheel with claws round the rim (Fig. 1). Such a wheel can be rotated so that the claws project through an opening. They pass the opening at regular intervals, and can thus be used to give intermittent jerks to the film. An arrangement of this kind is used to drag the material forward in a sewing machine.

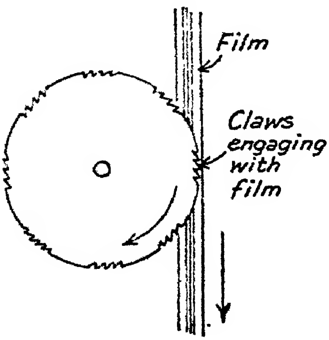


Fig. 1.

And so detail by detail projector and camera had to be thought out. As a guide there was the general idea of a roll of film jerked picture by picture through the gate of a projector, and rewound below.

Pioneer Troubles

One of the greatest troubles of the inventor is that in his own line he is a pioneer. The things he needs to test out usually do not exist, and there are no tools for making them. He has to improvise.

Baird's first television apparatus is an excellent example of the value of using improvised material. The things he needed had to be made specially for the job, but without special tools. The point was that the apparatus worked. The result was crude, but it was the kind of result Baird was looking for.

The most disheartening thing is to get no result at all, and everyone who aspires to be an inventor has to be prepared for such disappointments. The inventor does not easily give up hope. He may go through his apparatus, detail by detail, in the hope of finding something that may give the hoped-for result if it were altered. Then the inventor may have to put the apparatus away, and leave his sub-conscious mind to do a little work for him.

It may turn out that the principle on which he is working

appears to be all wrong. He may have to approach the matter again from another angle. In the early days of television many people thought it would always be impossible because of the difficulty of "scanning" the scene, that is, of moving a narrow beam of light to and fro across the picture many hundreds of times per second (Fig. 2). Any mechanical gadget, so they said, would be

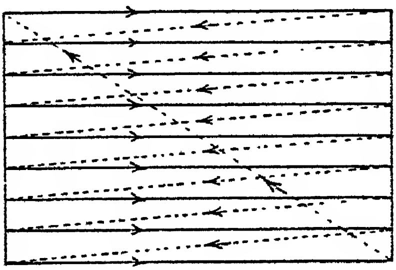


Fig. 2.

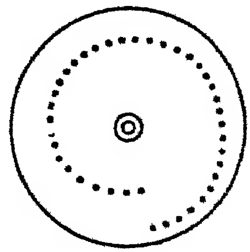


Fig. 3.

racketed to bits in no time by such movements. It did seem as if things had come to a dead end. Baird solved the problem by substituting circular movement for the to-and-fro movement (Fig. 3), and it has since been solved more completely by using a beam of electrons.

Mechanical Gadgets

An inventor who is working on something mechanical has to have a considerable knowledge of what it is possible to accomplish by mechanical means. Many mechanical devices are quite simple in themselves, but it is not always so simple to apply them to new problems.

There are more ways than one of driving a piston to and fro. There are variants on the old water-wheel, some of them adapted to being driven by compressed air—the flywheels of gyroscopes on aeroplanes, for example. There are the various forms of fan, centrifugal pump and air-screw. Rotary motion can be transmitted by means of bands, chains, and gear-wheels. We can gear up the speed of rotation or gear it down.

For intermittent movement we have the invaluable cam, which can have just as many forms as we like. Suppose we have a revolving shaft. We want a valve to remain closed for a whole revolution of the shaft, then to open gradually for half a revolution, shut suddenly, open gradually again, and shut suddenly at the end of the second revolution. Try to solve that simple mechanical problem before you read on.

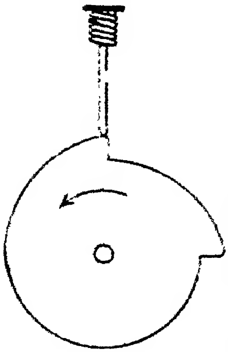


Fig. 4.

The cam-shaft must revolve once whilst the power-shaft revolves twice. It must be geared down by giving it a gear-wheel in mesh with a wheel on the power-shaft which has only half as many cogs. The cam is circular for half its circumference (Fig. 4), then rises through a quadrant up to the height necessary to open the valve; then there is a sudden drop, and another similar rise in the next quadrant.

Valves

There is a great variety of valves available to the inventor (Fig. 5). A valve is simply a one-way door. The *clack valve* is a hinged metal disk which is readily pushed open from below, but which drops and closes with a clacking noise when there is any downward pressure above it. A *throttle valve* is a similar disk which opens or shuts to control the supply of steam or petrol to an engine; it is sometimes opened or closed by means of a wheel or lever, and sometimes it is operated by a governor. A *check valve* may be a ball resting on a narrow part of a pipe; liquid pressed up from below raise the ball but the ball falls back and closes the pipe if th

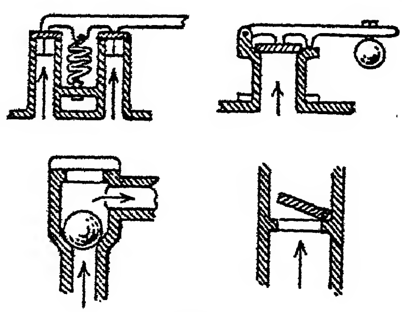


Fig. 5.

liquid falls or is pressed down. A *slide valve* consists of an opening across which a flat piece of metal slides to and fro, opening or closing it.

Governors

The governor is a very important part of an engine. Its purpose is of course to keep the engine running at a steady rate, neither too fast nor too slow. The object is to reduce the supply of steam or gas when the engine begins to run too quickly, and to increase it when the engine runs too slowly. A common form consists of heavy balls at the lower ends of short levers. A central axis is geared to the rotating shaft and revolves with it. When the engine uns too quickly the balls swing out, and this movement s used to shut off part of the supply of steam or gas. When the engine runs too slowly the balls fall in; this movement is used to admit a larger supply of steam or gas.

The thermostat is a kind of governor used to maintain a steady temperature. In a very simple form it consists of a long rod with one end fixed and the other over the mouth of the pipe that admits gas. When the temperature is unduly high the rod expands and closes the opening, thus reducing the supply of gas. When the temperature is unduly low the contracted rod leaves a wider space for gas to flow in.

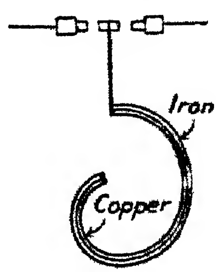


Fig. 6.

In another form two loops of metal, say copper (or brass) and iron, are bolted together (Fig. 6). One end of the loop is fixed; the other is attached to a pointer. Suppose the copper is on the inside; copper has a greater expansion than iron. An increase in temperature, therefore, opens out the loop, and so moves the pointer. A decrease in temperature closes in the loop and moves the pointer in the opposite direction. The changes in the position of the pointer can be used to make electrical contacts, and so to control some method of altering the temperature. Flues may be opened or shut, the supply of fuel increased or decreased, and so on.

Elaboration of Inventions

In their original forms inventions are often very simple. Improvements may be added one by one until the simple machine becomes extremely complicated.

Some of the complications may be profitable in a very large machine, and yet out of place in a small machine of the same kind. If we want to reduce the number of complications there are usually two ways of doing it. We can consider the complications one by one and decide how each can be modified or omitted altogether. The other method is to reconsider the whole problem; we have to consider what is necessary to achieve the object in view, and then to find the best way of doing it.

The great advantage of the second method is this: the original inventor found a way of making his machine work, but *it may not have been the best way*. Later inventors added improvements, but still the original fault remained. A re-inventor, starting again at the beginning, may hit on a device that will radically change the machine to its great advantage.

Suppose we want a small cinematograph projector. We can take the large projector as it is used in picture houses, and we can reduce it in size, with any necessary adaptations. Or we can start with the small number of necessities in a small projector, and create a machine that contains these.

The present two-stroke cycle engine resulted from a reconsideration of the whole problem. The old valves, held down by springs and opened by cams, were replaced by the much simpler and more efficient sleeve valve.

I have tried to make clear at least some of the qualities that make an inventor. Add to them an insatiable curiosity. We want to know how every bit of mechanism works. And why. Why put in this gadget? Why put in that? Wouldn't something else do instead?

I have no doubt that the quality of inventiveness can be cultivated. It is not given to everybody to perfect so large a thing as television. But think of the number of times in a year that you say or hear someone else say "If only we had——," "If only we could——." Those are the things the inventor follows up with hard and purposeful thinking and experiment.